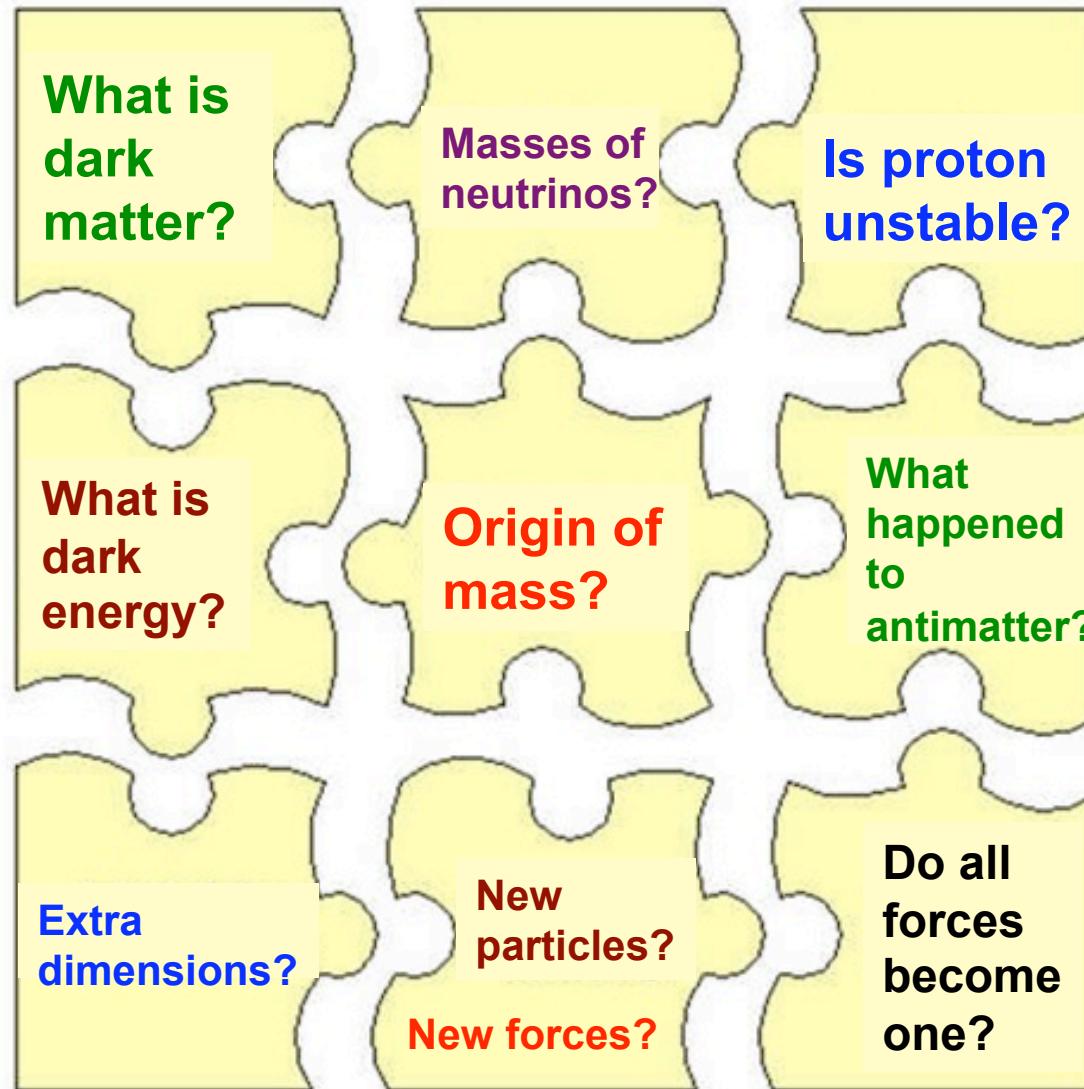


# Solving Great Puzzle: Search for Higgs Boson and New Physics

Sasha Pranko

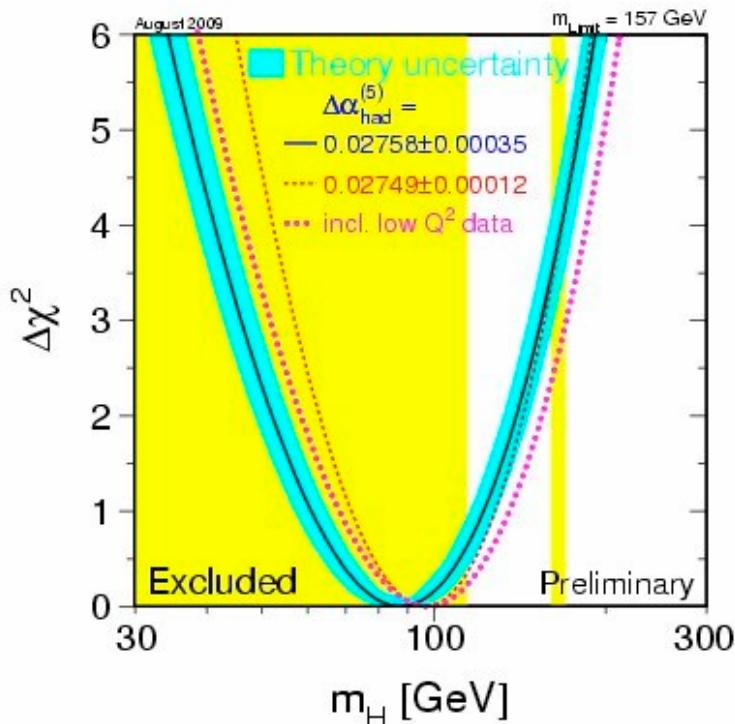
Fermilab

# Great Puzzle



# EWK Symmetry Breaking and Origin of Mass

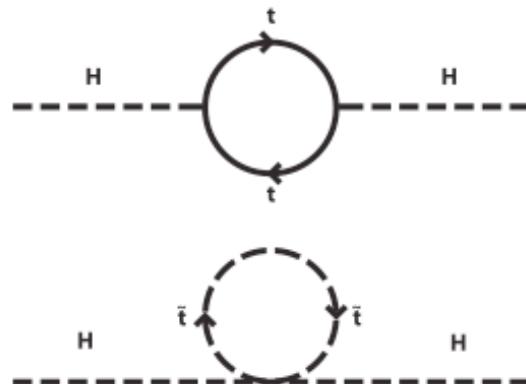
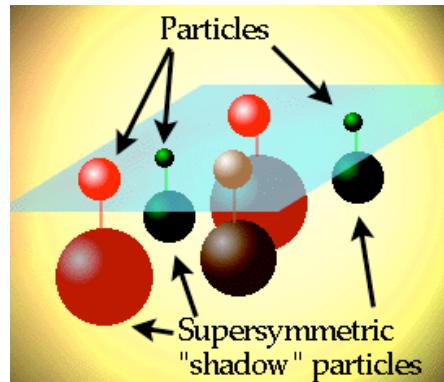
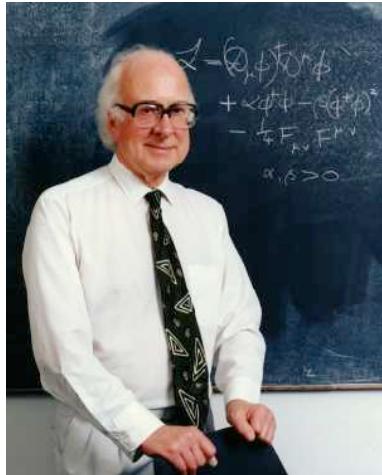
- Scalar Higgs field in SM
  - Source of EWK symmetry breaking
  - Higgs field  $\otimes$  particle field = mass



- Is SM Higgs Boson light?
  - Direct search at LEP & Tevatron
    - $114 \text{ GeV} < M_H < 163 \text{ GeV}$  at 95% CL
  - Indirect search: EWK fits
    - $M_H < 157 \text{ GeV}$  at 95% CL
    - $M_H = 87^{+35}_{-26} \text{ GeV}$  (at 68% CL)

# Higgs Boson is Just a Part of the Story...

If “SM” Higgs boson found



No “SM” Higgs boson

- More complex Higgs?
- Technicolor?
- Composite Z/W?
- Topcolor?
- Extra dimensions?
- .....
- **No deficit of models**
  - Some models can co-exist with “SM” Higgs

# There Must Be Something Beyond SM... But What?

- New Physics may show up before we can see Higgs (if exists)
- How do you look for something you don't know?



- **Some “search recipes”...**
  - Favorite signature of favorite model...
    - Chances for success?  $< 1/(\# \text{ of HEP scientists})$
  - (Global) model-independent search...
  - Study to death “tails” of SM processes...
  - Look at rare SM signatures...
  - Be vigilant & follow up on nature’s hints...
  - ....

**After discovery we'll know which strategy was the best one...**

# In This Talk...

- Search for anomalies in  $\gamma\gamma + \text{MET}$  at CDF
  - Potential for discovery
  - Know-how in photons & MET

Searching for unknown

- Observation of  $VV \rightarrow jj + \text{MET}$  at CDF
  - Milestone in  $ZH \rightarrow bb + \text{MET}$  search
  - Tools for Higgs search

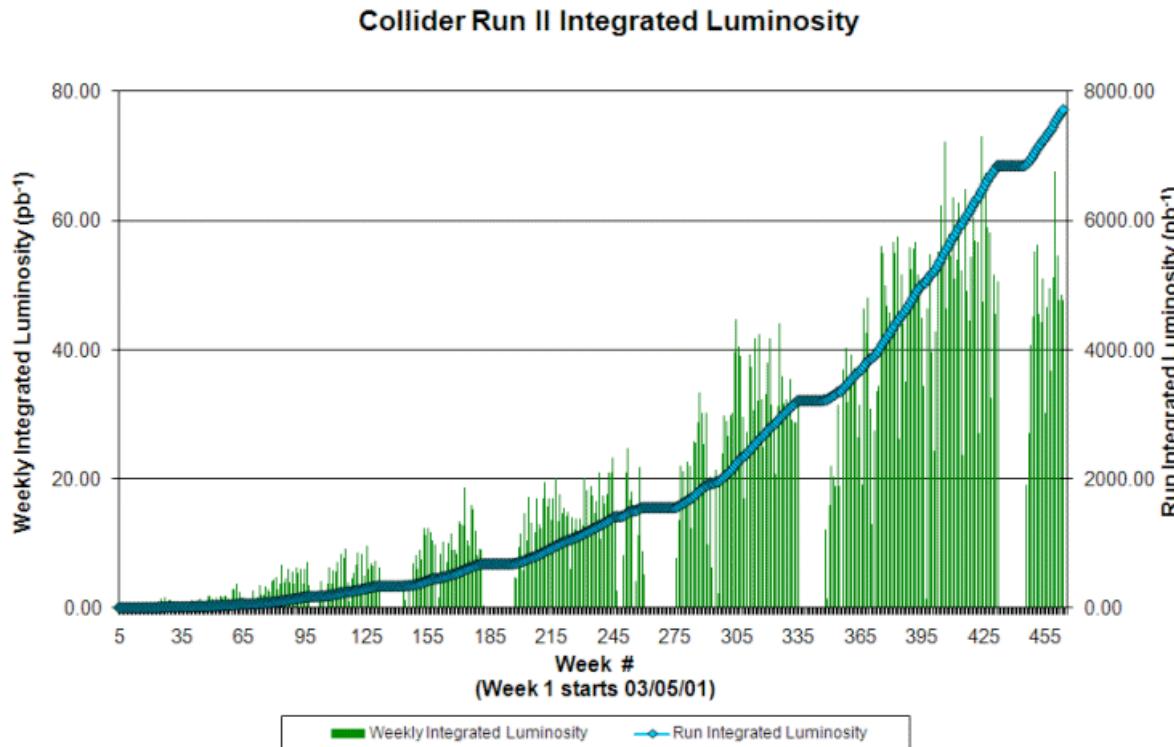
On the road to Higgs

- Inclusive  $H \rightarrow \tau\tau$ 
  - New ideas for CDF & ATLAS

Future Higgs searches

**Grand problems require innovative solutions**

# Race for Higgs: Sprint or Marathon?



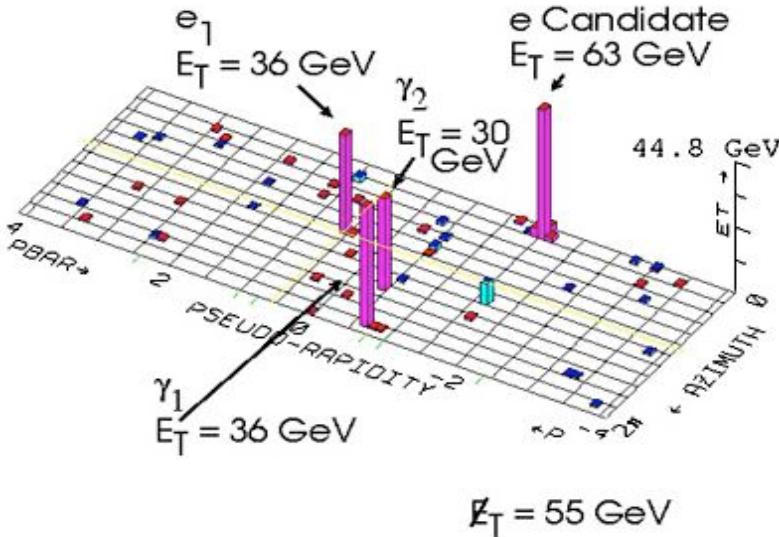
- Produced in  $1 \text{ fb}^{-1}$ 
    - $\approx 6.2\text{M } W \rightarrow l\nu + X$
    - $\approx 2.6\text{M } Z \rightarrow \nu\bar{\nu} + X$
    - $\approx 5.1\text{K } WW \rightarrow jjl\nu$
    - $\approx 1.3\text{K } WZ \rightarrow jjl\nu + jj\nu\nu$
    - $\approx 0.4\text{K } ZZ \rightarrow \nu\nu jj$
    - $\approx 33 \text{ } WH \rightarrow l\nu bb ??$
    - $\approx 13 \text{ } ZH \rightarrow \nu\nu bb ??$
- $l = e, \mu, \tau; M_H = 120 \text{ GeV}/c^2$

- Tevatron:  $\sim 7.8 \text{ fb}^{-1}$  per experiment
  - Expect  $10-12 \text{ fb}^{-1}$  per experiment by the end of 2011
- Higgs results from Tevatron will dominate at least until 2012

# Search for New Physics in $\gamma\gamma + \text{MET}$ Events

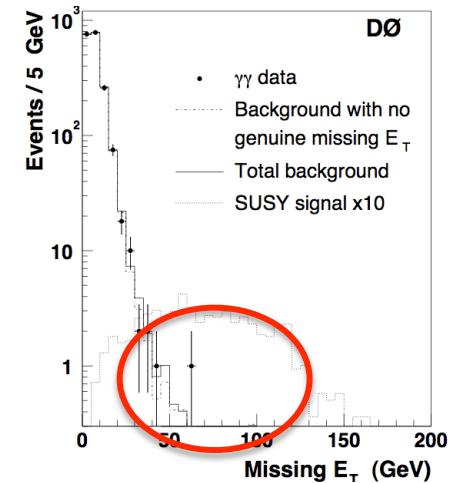
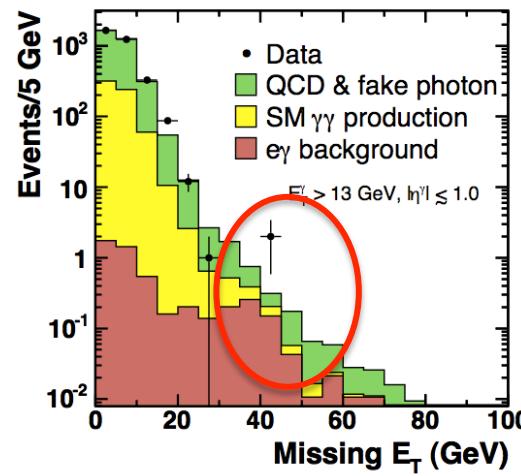


# Why $\gamma\gamma + \text{MET}$ ?



- Rich physics
  - Many models
  - Gauge Couplings
- Experimental know-how
  - Photon & MET techniques

- Surprise in Run-I
  - Data:  $ee + \gamma\gamma + \text{MET}$  event
  - SM background:  $10^{-6}$  expected
- Early Run-II results
  - CDF:  $202 \text{ pb}^{-1}$ , PRD 71, 031104
  - D0:  $263 \text{ pb}^{-1}$ , PRL 94, 041801
  - Events on tails of MET distribution



# Which Model to Pick?

SUSY:  $\gamma\gamma + \cancel{E}_T$ ,  $\gamma\gamma + jets + \cancel{E}_T$ ,  $\gamma\gamma + ll + \cancel{E}_T$

Technicolor:  $\gamma\gamma + ll + \cancel{E}_T$

Higgs:  $\gamma\gamma + \cancel{E}_T$ ,  $\gamma\gamma + l + \cancel{E}_T$

UED(6DSM):  $\gamma\gamma + m^* l + \cancel{E}_T$

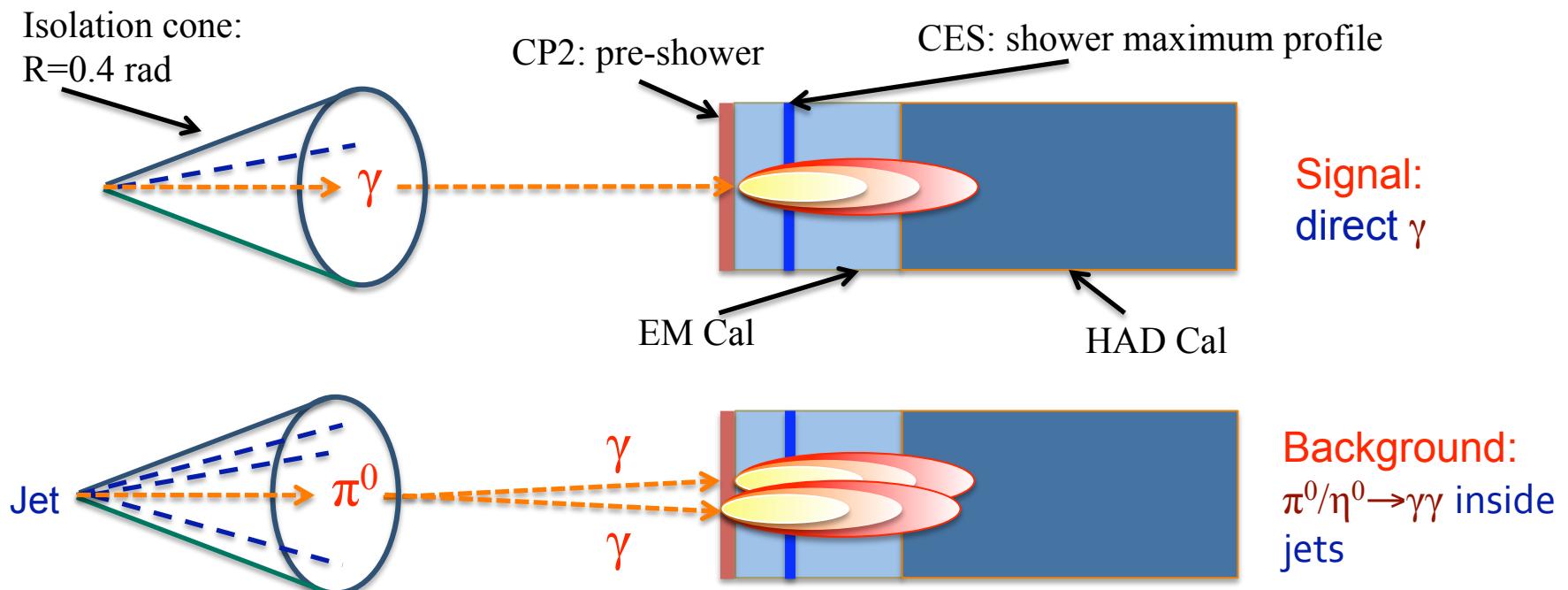
- Take “hybrid” approach:
  - Do model-independent analysis
  - Set limits on model of most impact (often subjective criteria)



- Typical week at arXiv: ~100 papers
  - hep-ph daily 11 new + 3 crosses received
  - hep-ph daily 14 new + 4 crosses received
  - hep-ph daily 14 new + 5 crosses received
  - hep-ph daily 33 new + 4 crosses received
  - hep-ph daily 7 new + 3 crosses received

# Concept of Photon ID

- Photon detector signature
  - “Compact”, isolated EM cluster: shower contained in EM CAL without much other energy around
- What fakes a photon?
  - Energetic ( $\approx$ boosted)  $\pi^0/\eta^0 \rightarrow \gamma\gamma$  looks like a single photon
  - Electron  $\approx$  photon + track



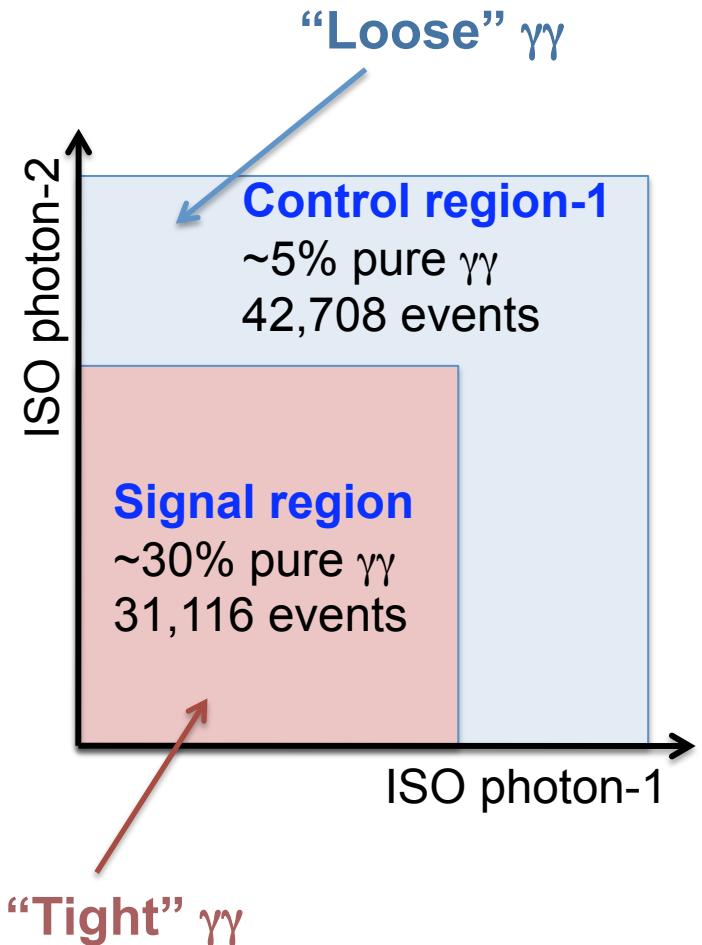
# “Roadmap” for $\gamma\gamma + \text{MET}$ Analysis

- **Signal & control samples**
- **QCD background**
- **EWK background**
- **Non-collision backgrounds and QCD pathologies**
- **Model-independent results and limits on GMSB**



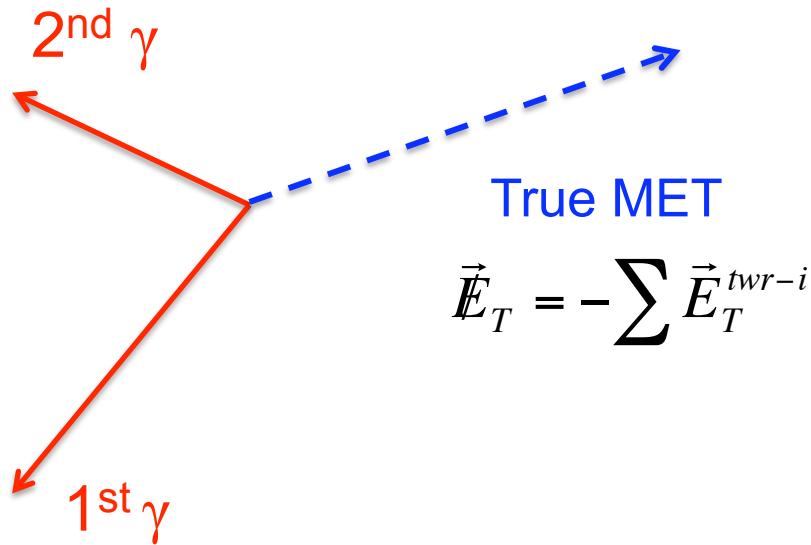
# $\gamma\gamma + \text{MET}$ Analysis: Signal & Control Samples

- **Signal region:** “tight”  $\gamma\gamma$ 
  - 2 photons:  $E_T > 13 \text{ GeV}$ ,  $|\eta| < 1.1$
  - $2 \text{ fb}^{-1}$  of data
- **Control region-1:** “loose”  $\gamma\gamma$ 
  - Same topology & backgrounds
  - Test analysis procedure
- **Control region-2:** “tight”  $e + \gamma$  events
- **Control region-3:** “loose”  $e + \gamma$  events
  - Same event selection
  - Check of EWK backgrounds

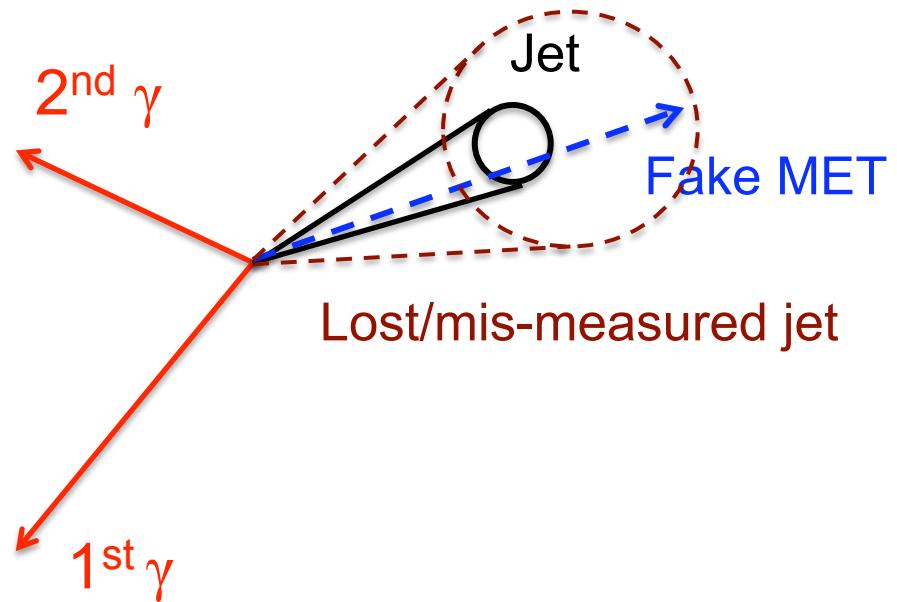


# “QCD” background: SM $\gamma\gamma$ Events with Fake MET

Signal candidate



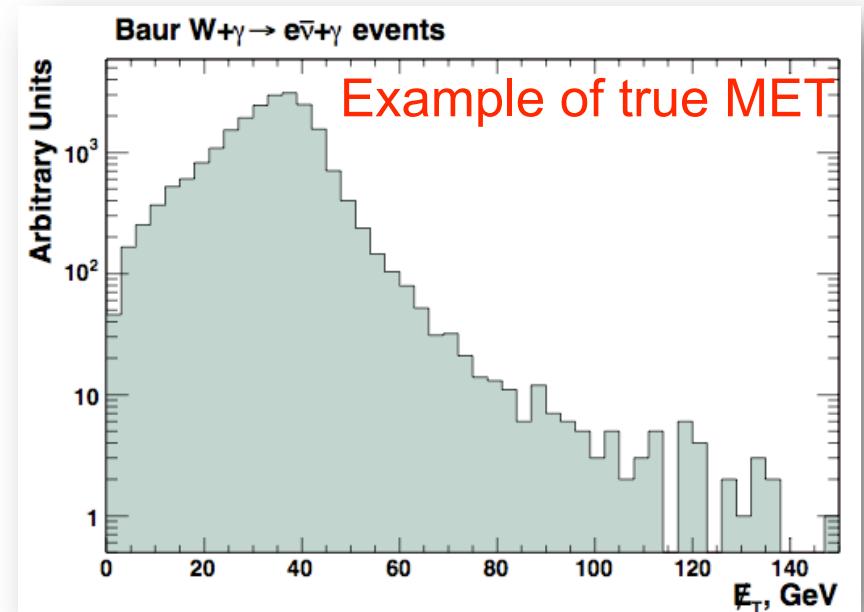
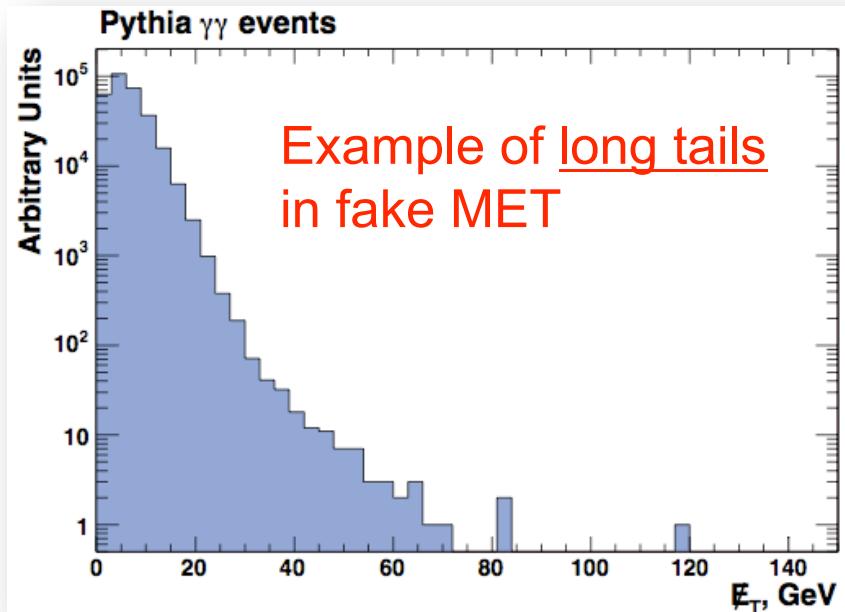
“QCD” background



- Both photons and MET are genuine
  - MET can be due to **neutrino** or **new particles** not interacting with detector

- SM  $\gamma\gamma+N$ -jet events
  - One or both photons can be fakes
  - Lost or mis-measured jet gives fake MET

# Fake MET Problem in $\gamma\gamma$ +MET Search

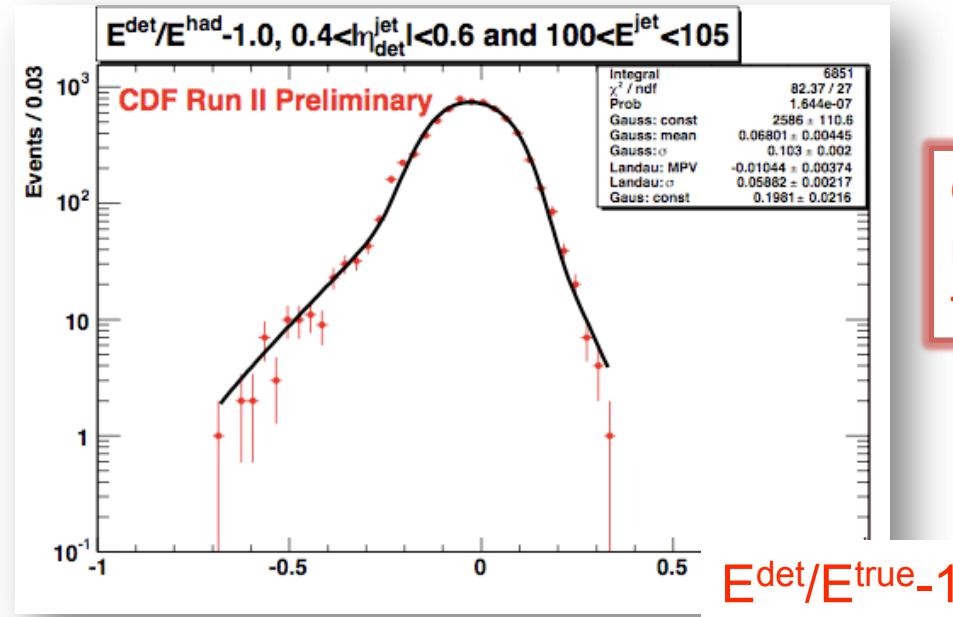


- MET distribution in  $\gamma\gamma$  events is dominated by regular “QCD” events with fake MET
  - MC is not reliable in modeling multi-jet events:
    - not accurate description of fake MET
- How do you distinguish events with true & fake MET?

# Met Resolution Model (*METMODEL*)

Example of jet energy resolution

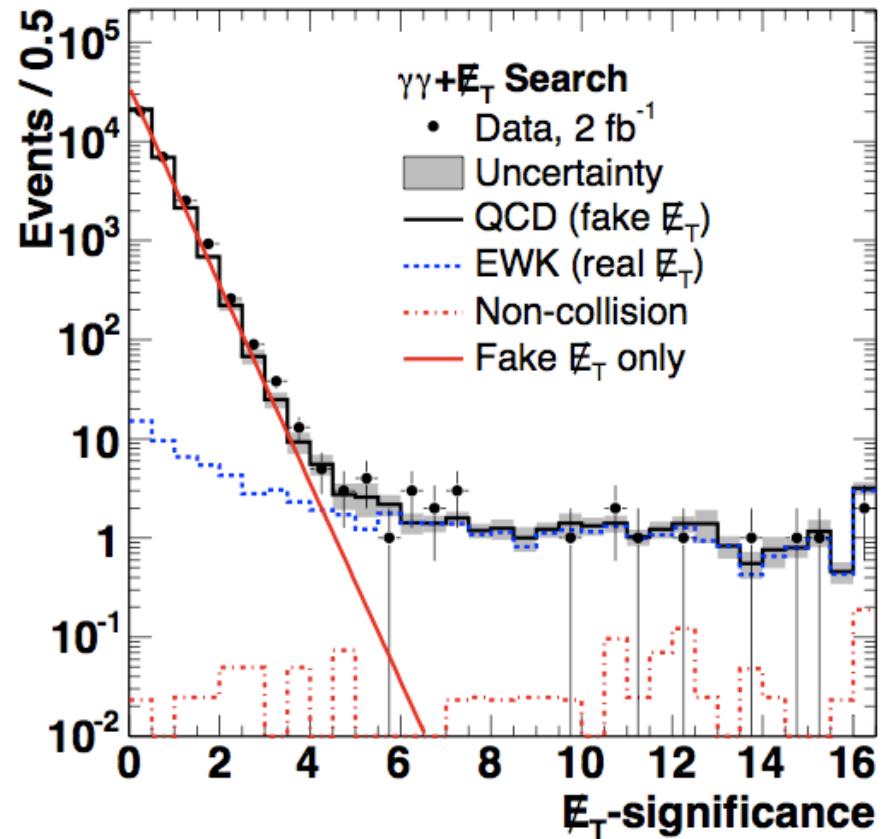
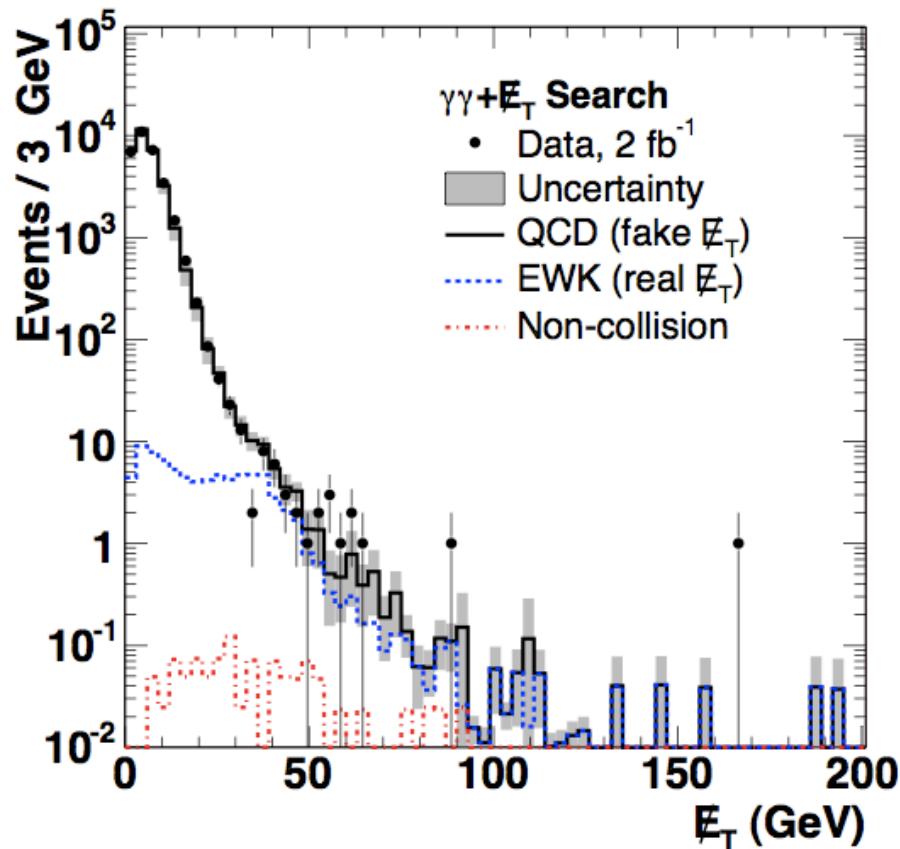
Mis-measurements  
in jet energy are  
leading source of  
fake MET



Obtain jet energy  
resolution as  
function of  $E^{\text{jet}}$  &  $\eta$

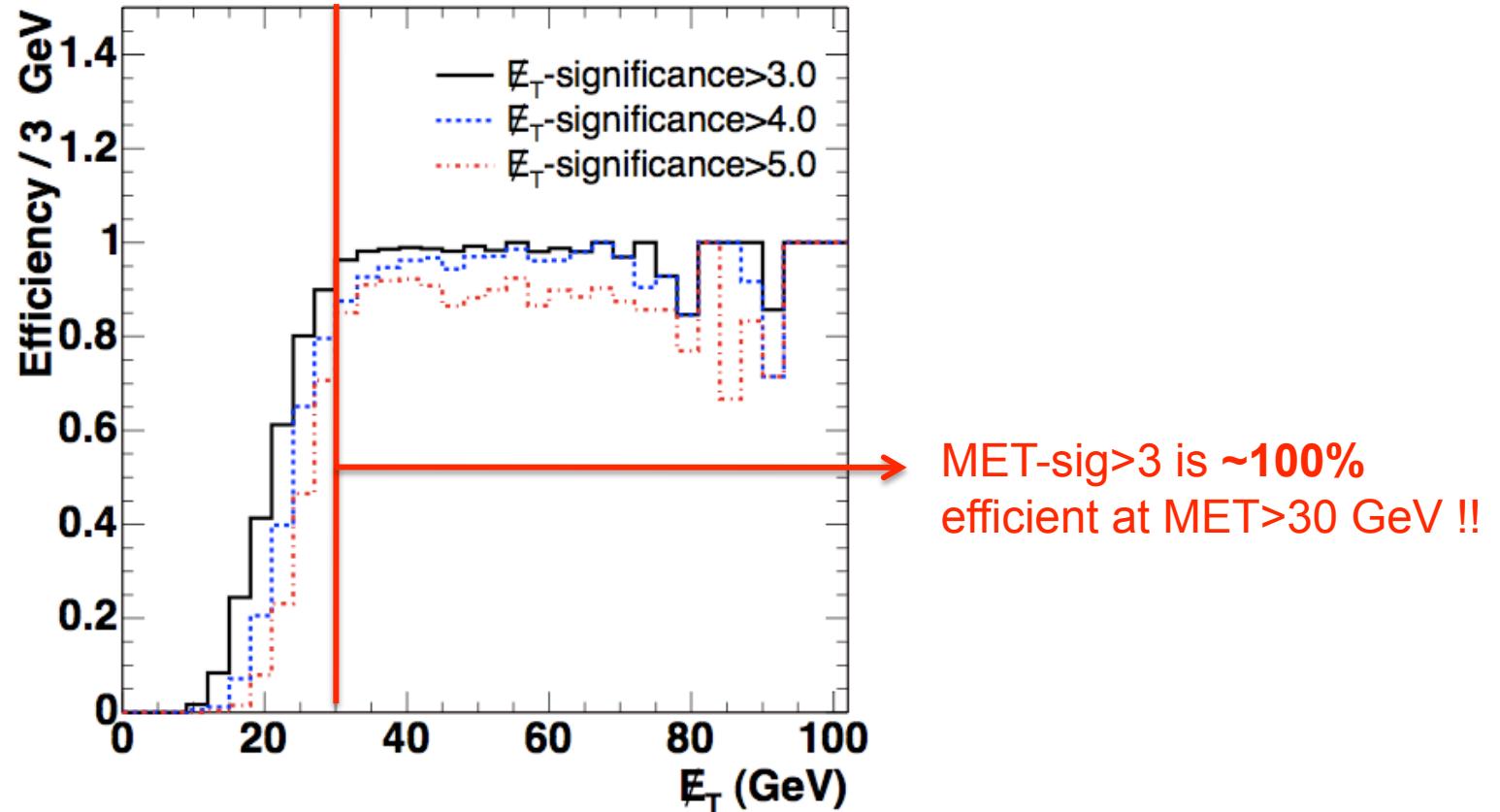
- Predicting fake MET
  - Smear jets & soft particles in  $\gamma\gamma$  events according to energy resolution
- Select events with true MET
  - Use MET-significance to select with true MET
  - Calculate MET-significance based on event configuration & known energy resolution

# MET-significance Effectively Separates True & Fake MET



- Select events with MET-significance  $> 3, 4, \text{ and } 5$ 
  - Suppress QCD by 3, 4, and 5 orders of magnitude, respectively
  - METMODEL: data-based fake MET predictions

# MET-significance Very Effective for True MET



- Efficiency of MET-significance cut for events with true MET (e.g.,  $W\gamma \rightarrow e\nu\gamma$ )

Efficiency for $W+\gamma \rightarrow e\nu+\gamma$	MET-sig>3.0	MET-sig>4.0	MET-sig>5.0
	84%	74%	67%

# “Roadmap” for $\gamma\gamma + \text{MET}$ Analysis

- Signal & control samples
- QCD background
- EWK background
- Non-collision backgrounds and QCD pathologies
- Model-independent results and limits on GMSB



# EWK Backgrounds in $\gamma\gamma + \text{MET}$ Search

Process	MET-sig>3	MET-sig>5
$W(e\nu) + \gamma/\text{jet}$	46%	50%
$Z/W + \gamma\gamma$	35%	35%
$W(\tau\nu) + \gamma/\text{jet}$	11%	10%
$Z(\tau\tau) + \gamma/\text{jet}$	7%	5%

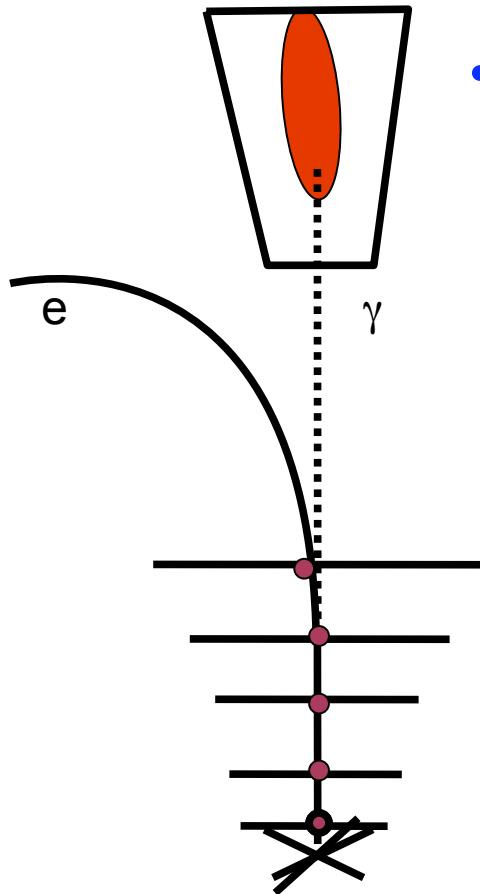
- EWK processes with genuine MET
  - Leptons faking photon: 65%
    - Fakes:  $e \rightarrow \gamma$  or  $\tau \rightarrow \gamma$
    - Note  $\tau \rightarrow \gamma$ : 15% - 18% of total EWK
      - Not considered in earlier analyses
  - Real photons: 35%

- MC EWK prediction normalized to data

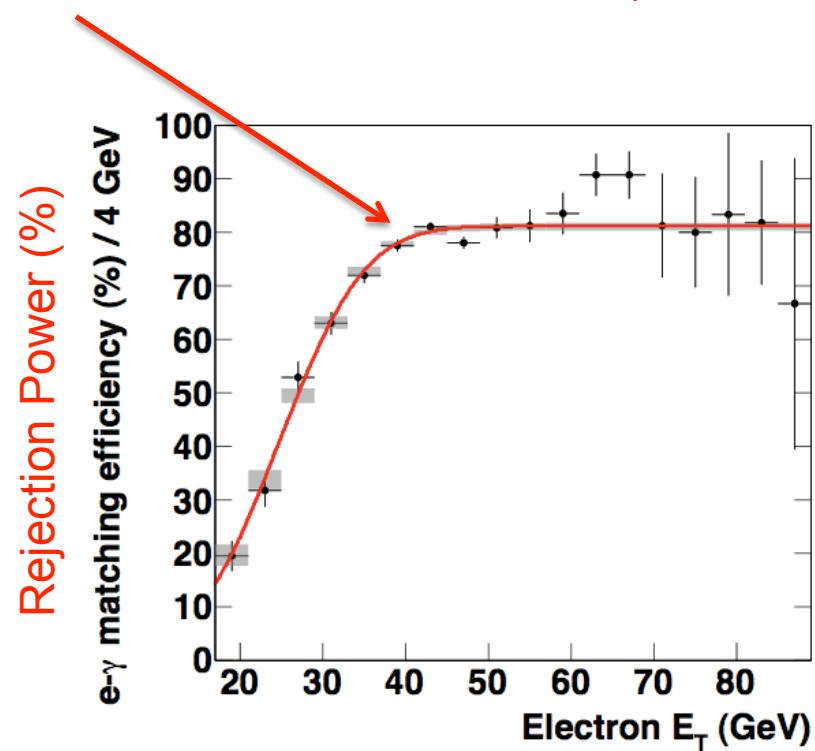
$$MC(\gamma\gamma + E_T) \times \frac{Data(e\gamma + E_T)}{MC(e\gamma + E_T)}$$

- X-check:
  - Repeat analysis with “loose”  $\gamma\gamma$  events

# Reducing $e \rightarrow \gamma$ Fake Rate



- Silicon “tracking” for photons
  - Originally developed for “forward” electrons
  - First applied in  $\gamma\gamma + \text{MET}$  analysis
  - Reduce  $e \rightarrow \gamma$  fake rate by up to 80% at  $E_T > 40 \text{ GeV}$

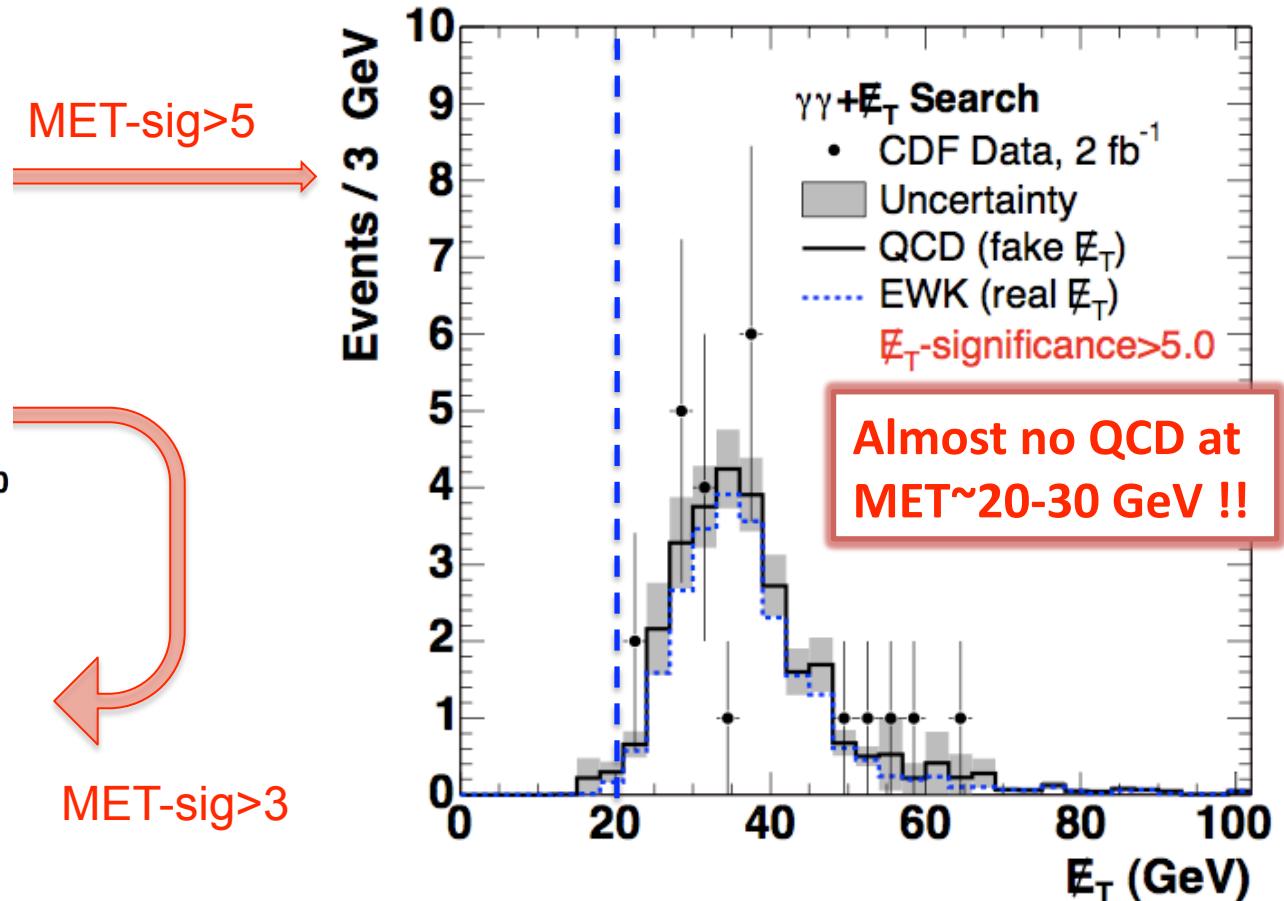
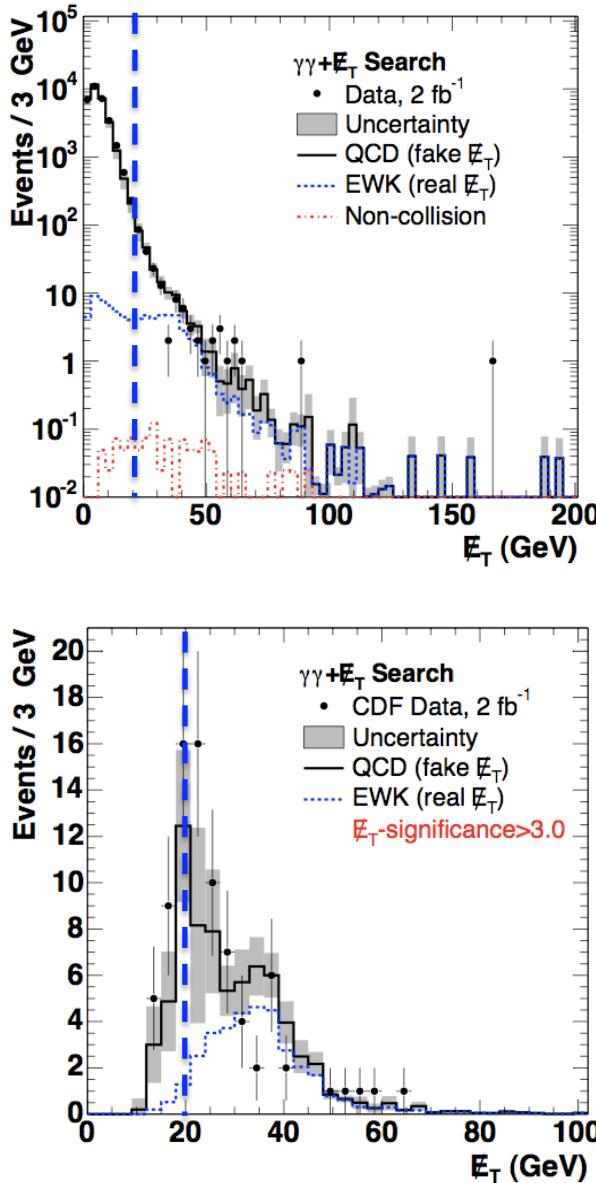


# “Roadmap” for $\gamma\gamma + \text{MET}$ Analysis

- Signal & control samples
- QCD background
- EWK background
- Non-collision backgrounds and QCD pathologies
  - Will skip, slides in backup
- Model-independent results and limits on GMSB

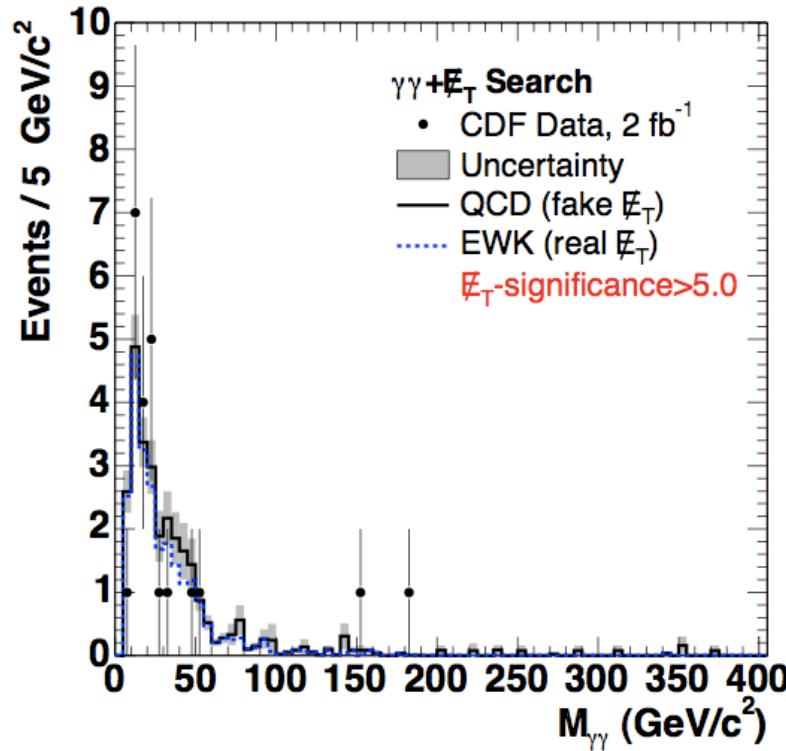


# No QCD Contamination in Selected $\gamma\gamma$ +MET Events !!

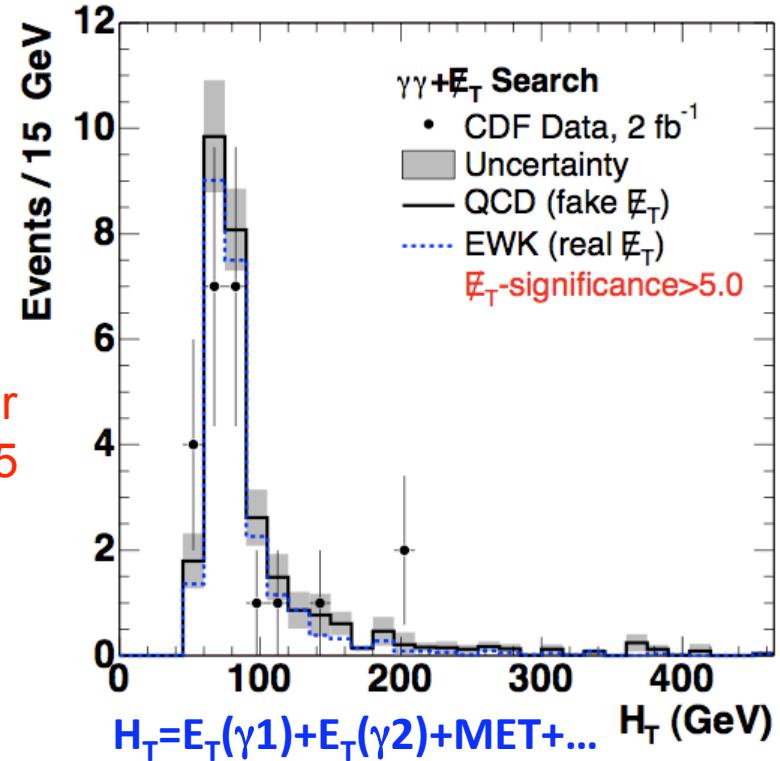


- Predictions agree with data in selected  $\gamma\gamma$ +MET events

# No Signs of Anomalies in Selected $\gamma\gamma + \text{MET}$ Events



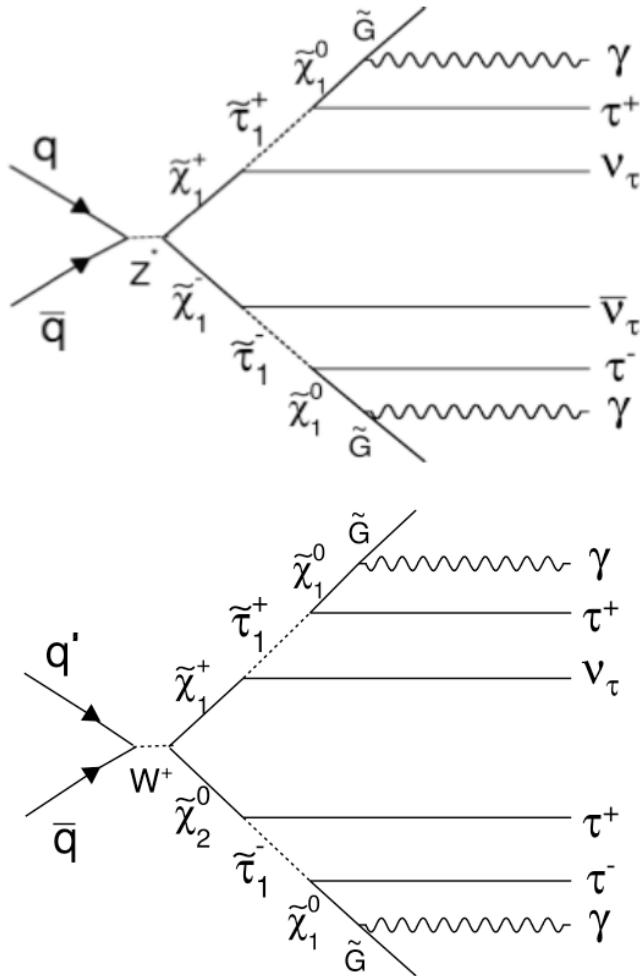
Results for  
MET-sig>5



- Studied many more distributions for MET-sig>3 and 5

	MET-sig>3	MET-sig>4	MET-sig>5
Background	$71.7 \pm 7.5$	$39.0 \pm 3.1$	$30.4 \pm 2.4$
Data, $2 \text{ fb}^{-1}$	82	31	23
EWK	49%	77%	85%

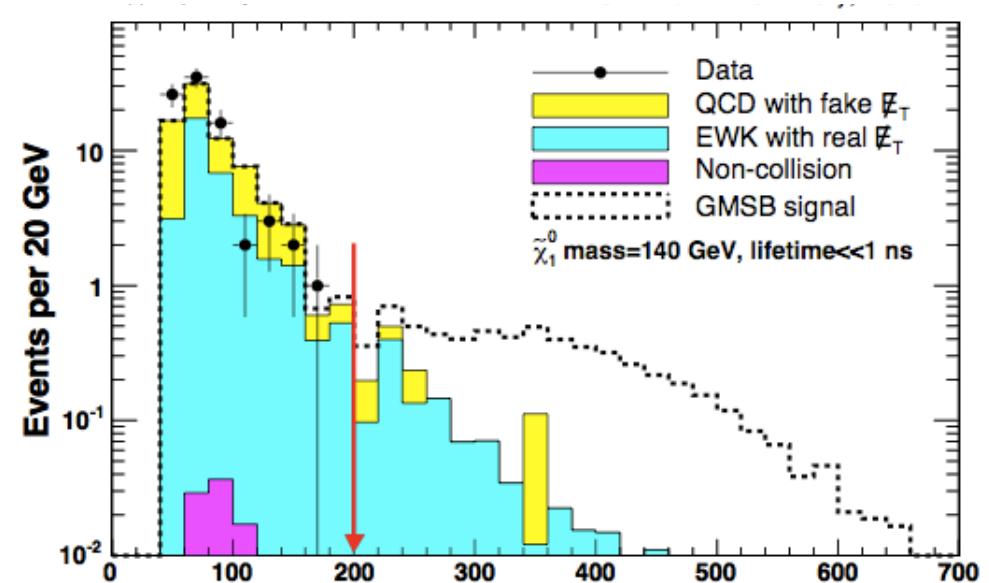
# Limits on GMSB in $\gamma\gamma+MET$ : Theory Overview



- **Gauge-Mediated SUSY Breaking**
  - One of the SUSY breaking scenarios
    - Only 6 free parameters
  - Gravitino LSP ( $<< \text{MeV}$ )
  - Neutralino or slepton (mostly stau) NLSP
  - Heavy squarks and gluinos
    - Not produced at Tevatron
  - If  $\chi^0$  NLSP:  $\chi^0 \rightarrow \gamma G$  (Br=100%)
    - Primary model for  $\gamma\gamma+MET$

# Limits on GMSB in $\gamma\gamma+\text{MET}$ : Analysis Overview

- 3D optimization:
  - MET-significance,  $H_T$ ,  $\Delta\phi_{\gamma\gamma}$
- Signal acceptance:
  - $7.80\% \pm 0.54\%$  at  $M_\chi = 140$  GeV
- Leading backgrounds:
  - $Z\gamma\gamma$ , QCD,  $W\gamma$



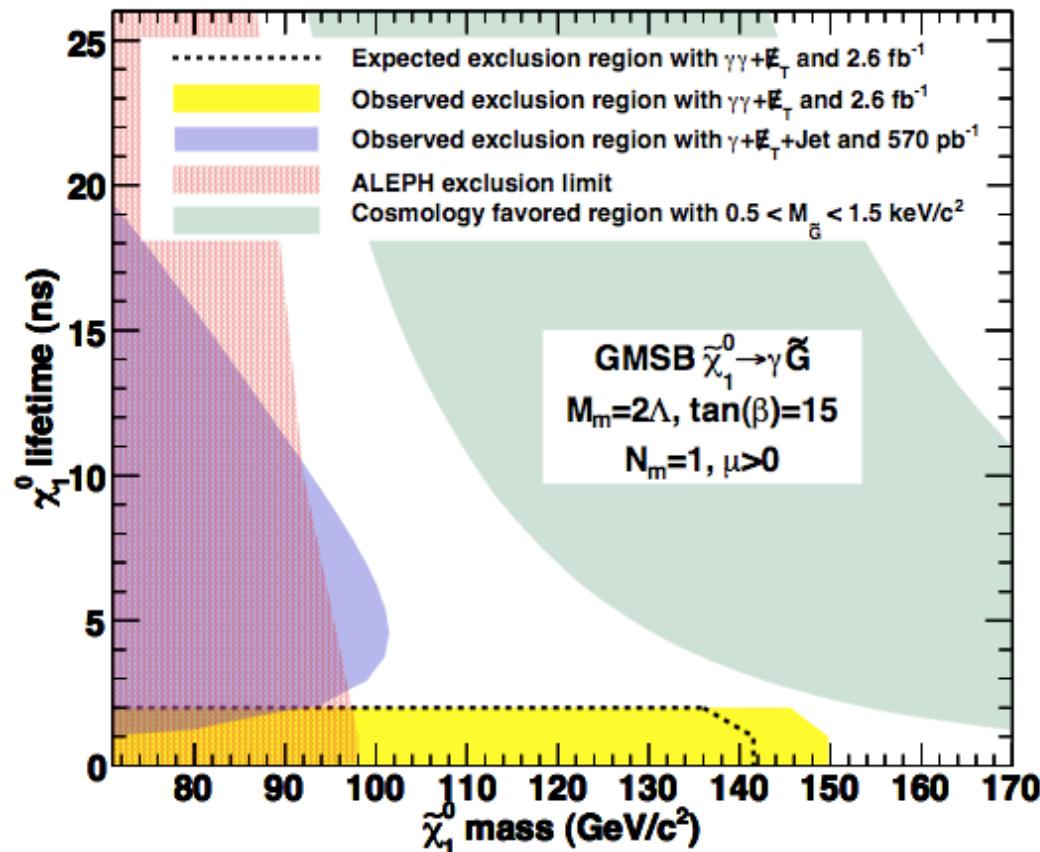
$$H_T = E_T(\gamma 1) + E_T(\gamma 2) + \text{MET} + \dots$$

After MET-sig>3 &  $\Delta\phi_{\gamma\gamma} < \pi - 0.35$

**Data: no events observed in  $2.6 \text{ fb}^{-1}$**

EWK	$0.92 \pm 0.21 \text{ (stat)} \pm 0.30 \text{ (syst)}$
QCD	$0.46 \pm 0.22 \text{ (stat)} \pm 0.10 \text{ (syst)}$
Non-Collision	negligible
Total background	$1.38 \pm 0.30 \text{ (stat)} \pm 0.32 \text{ (syst)}$

# World's Best Limit on GMSB with Neutralino NLSP

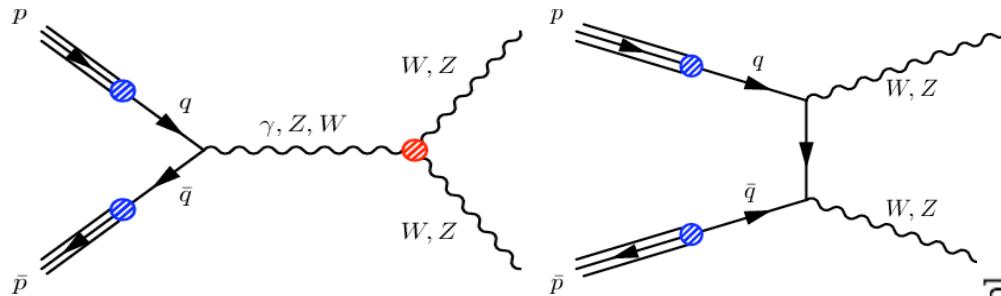


- 95% CL limits in neutralino mass & lifetime plane
  - Exclude neutralino mass  $< 149 \text{ GeV}/c^2$  for  $\tau \ll 1 \text{ ns}$ 
    - GMSB analysis: PRL 104, 011801 (2010)
    - Model-independent analysis: arXiv:0910.5170 (submitted to PRD)

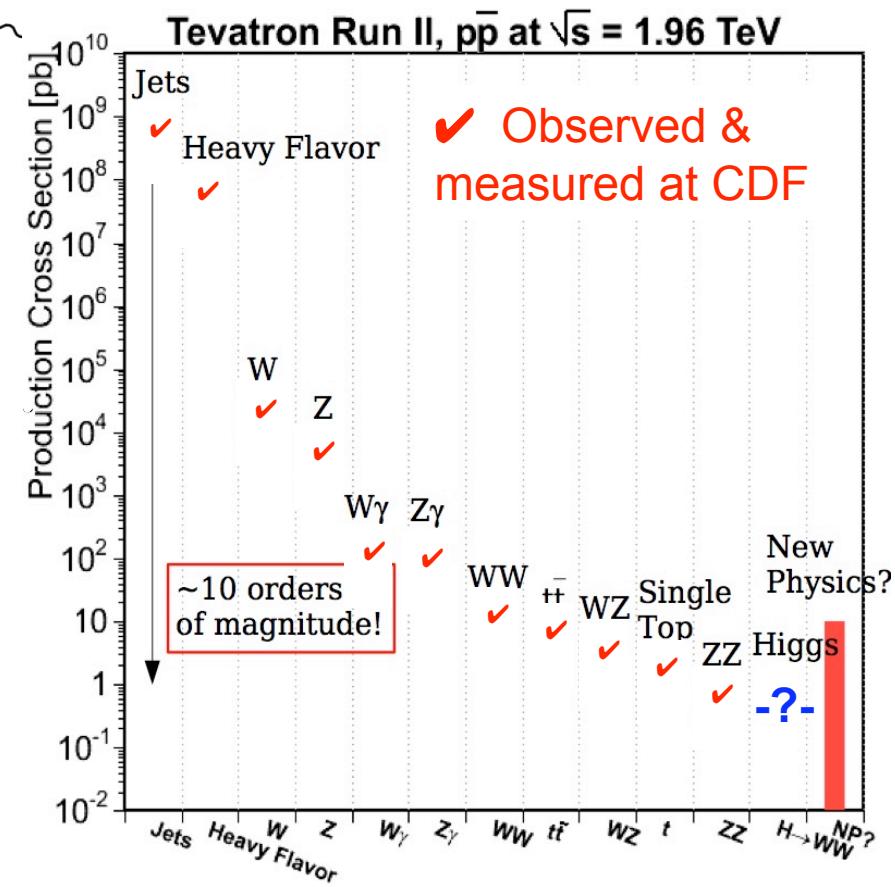


# **On the Higgs Highway: First Observation of Diboson Production in JJ+MET Final States**

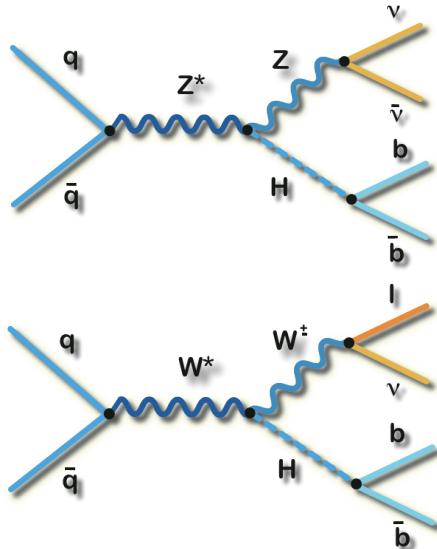
# Diboson Processes at the Tevatron



- EW boson self-interactions are completely dictated by gauge symmetry
- Sensitive to new physics
  - S-channel
    - Directly produced new particles
    - New Physics at large energy scale through loop effects

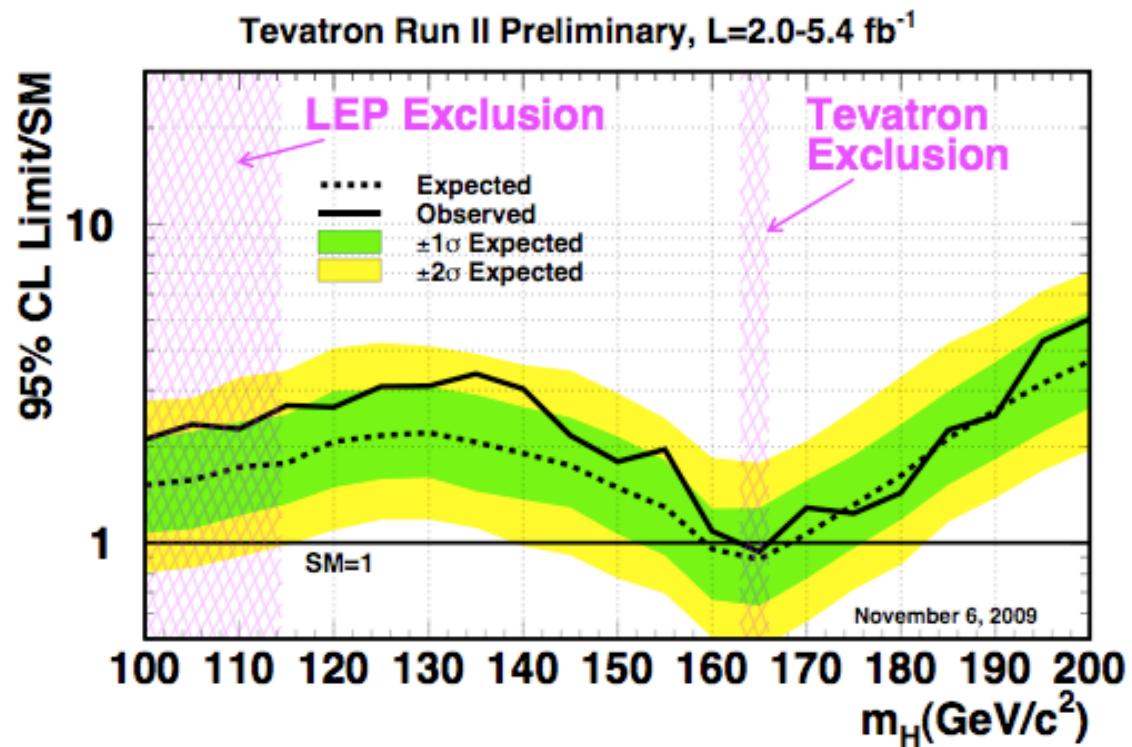
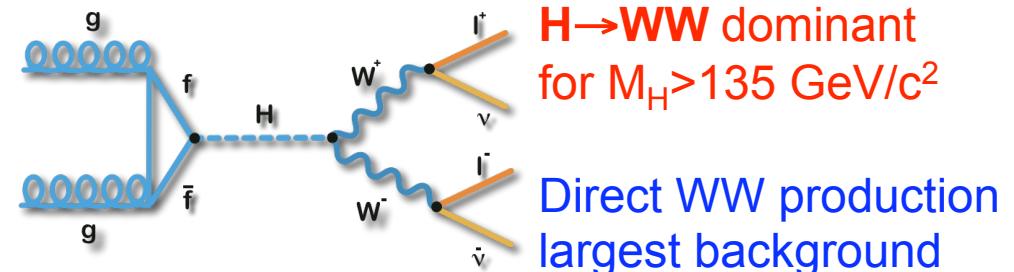


# Road to Higgs at Tevatron is Paved with Dibosons



**$H\rightarrow l\nu + bb$  &  $HZ\rightarrow \nu\nu + bb$**   
leading channels for  
 $M_H < 135 \text{ GeV}/c^2$

Similar signatures and challenges as in  
 $WW/WZ\rightarrow l\nu + jj$  &  
 $ZZ/WZ\rightarrow \nu\nu + jj$

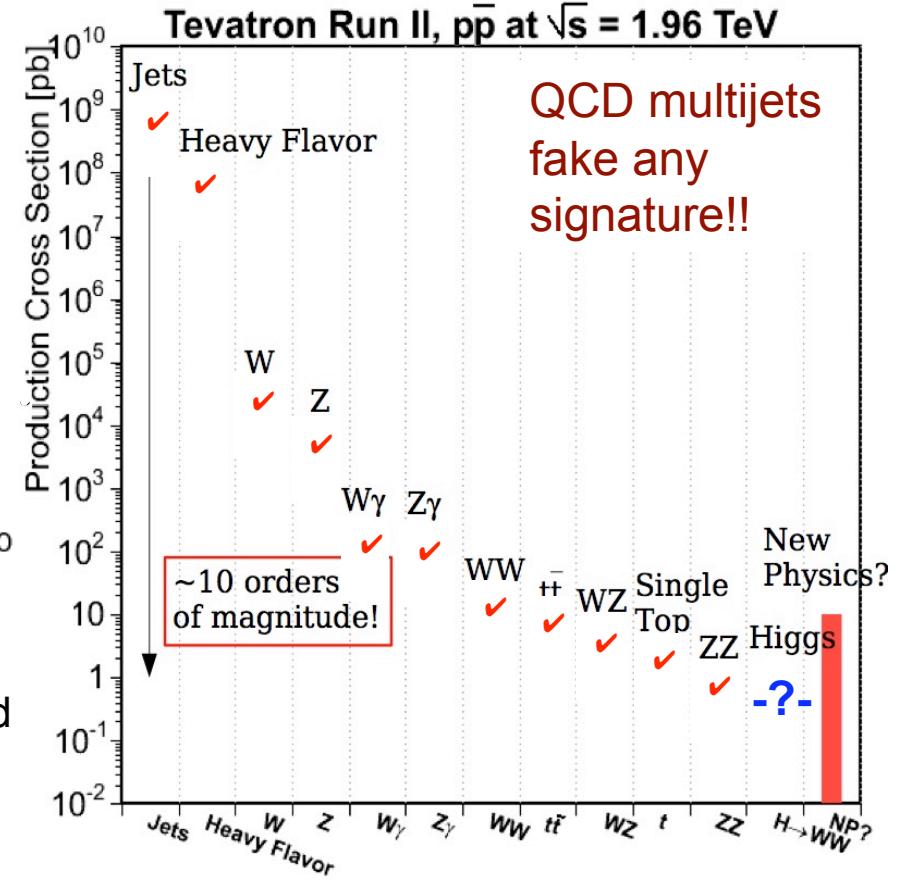
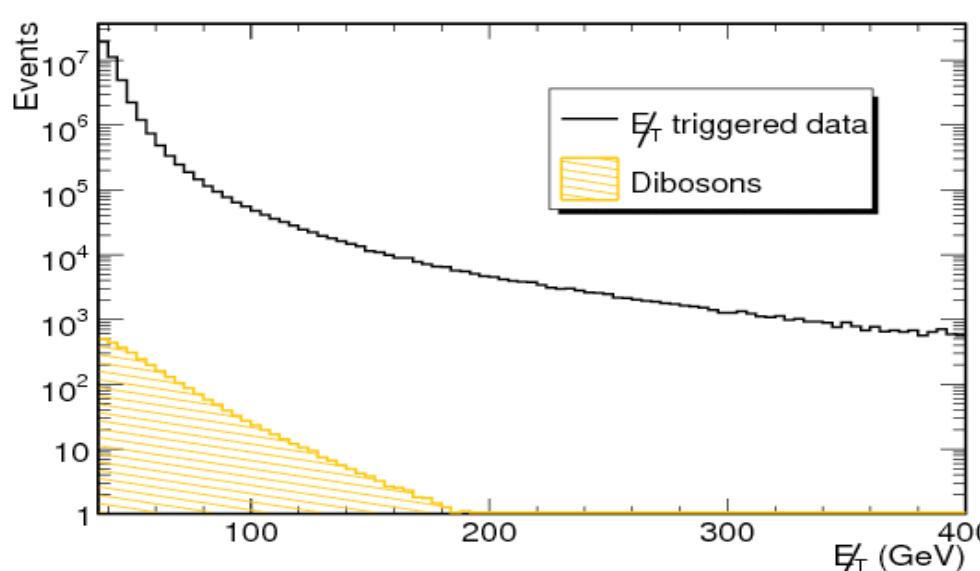


# “Roadmap” to Dibosons in jj+MET (With Higgs in Mind)



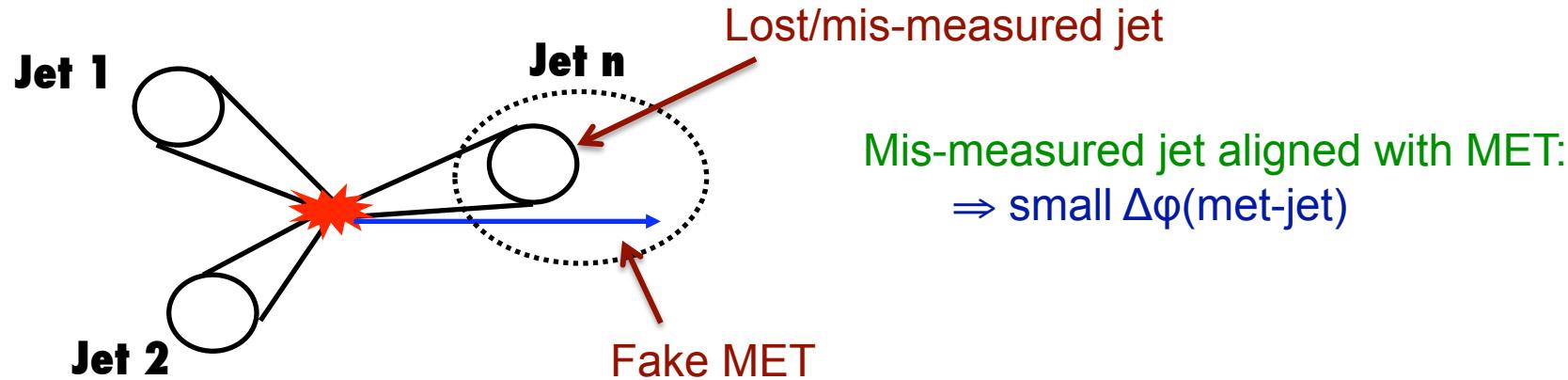
- Challenges
  - Small signal
  - Large backgrounds
- Maximize signal acceptance
  - Use all MET triggers
  - No lepton requirement/veto
    - sensitive to  $W/Z \rightarrow l\nu/\nu\nu$
- Develop and test new techniques
- Maximal use of data to estimate backgrounds

# Dibosons are Swamped with Backgrounds



- QCD  $\sim 9$  orders above WW+WZ+ZZ  
Rare fluctuations  $\times$  huge rate = large background
- Triggered data dominated by QCD events with fake MET
  - Rejecting QCD multijet events is a major challenge

# Diboson Candidates in $3.5 \text{ fb}^{-1}$ : 44,910 Events

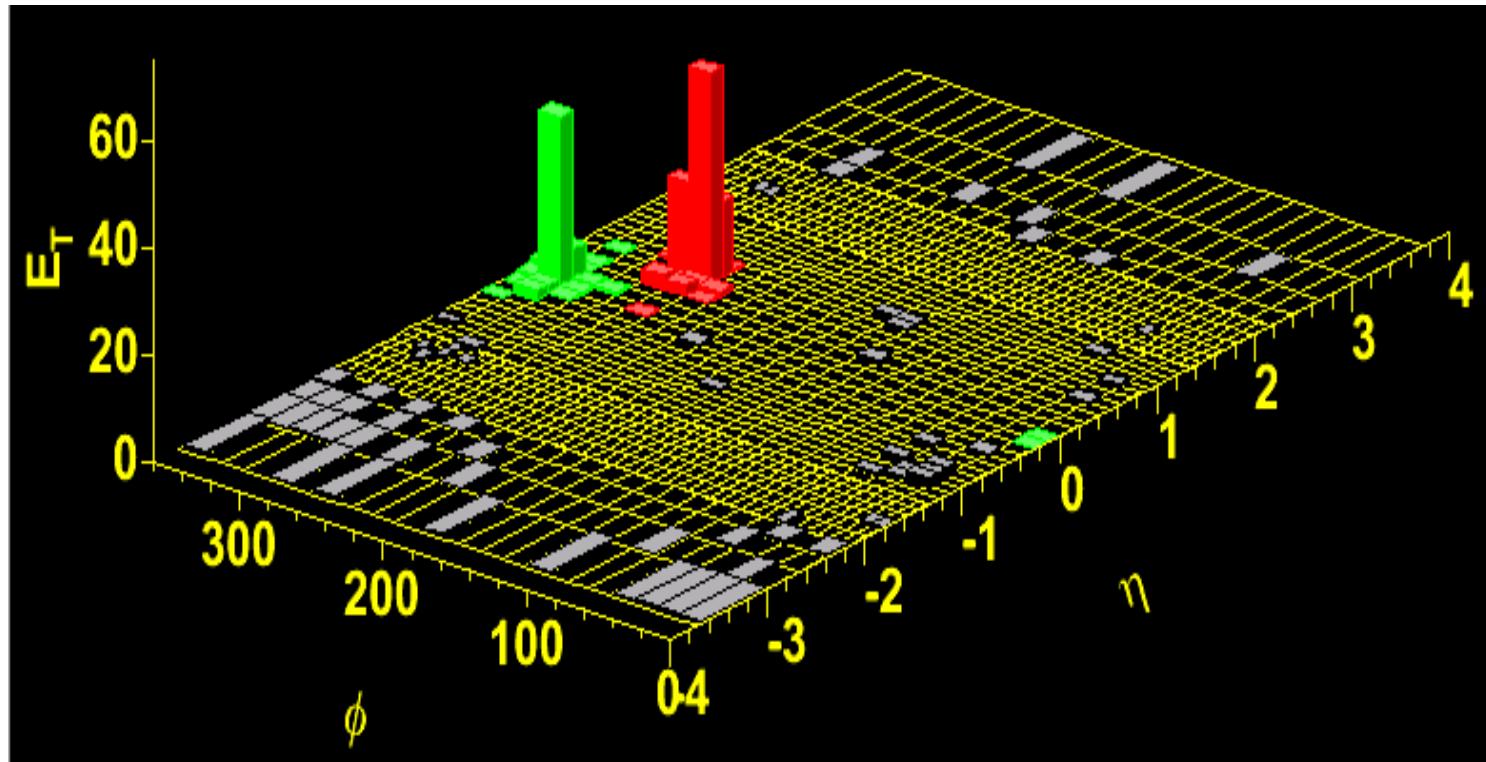


- Dealing with QCD background:
  - Reject as much as possible
  - Use data to model whatever remains

QCD rejection  
based on  
METMODEL

Variable	Cut values
MET	>60 GeV
Jet -1,2 $E_T$	>25 GeV
Jet -1,2 $ \eta $	<2.0
$\Delta\phi_{\text{met-jet}}$	>0.4 rad
MET-significance	>4
$M_{jj}$	40 – 160 $\text{GeV}/c^2$
Jet timing	<4.5 ns

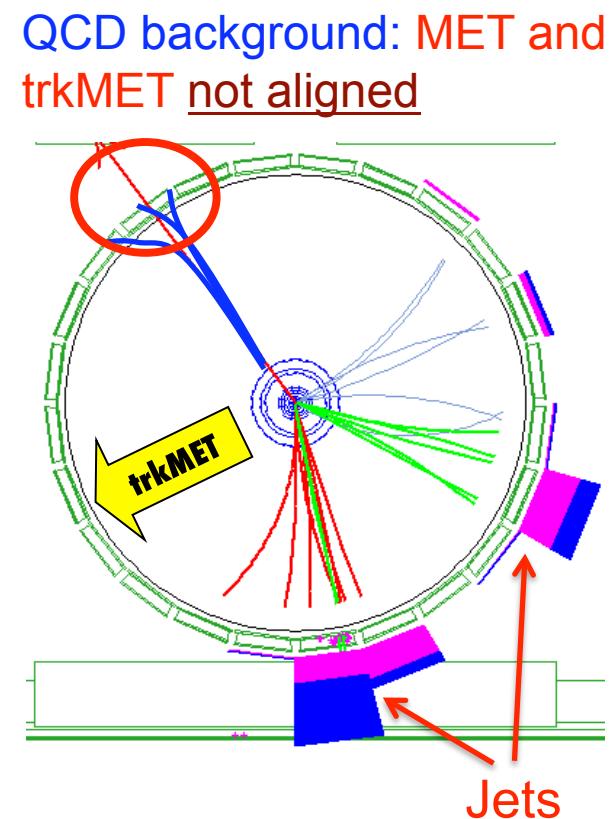
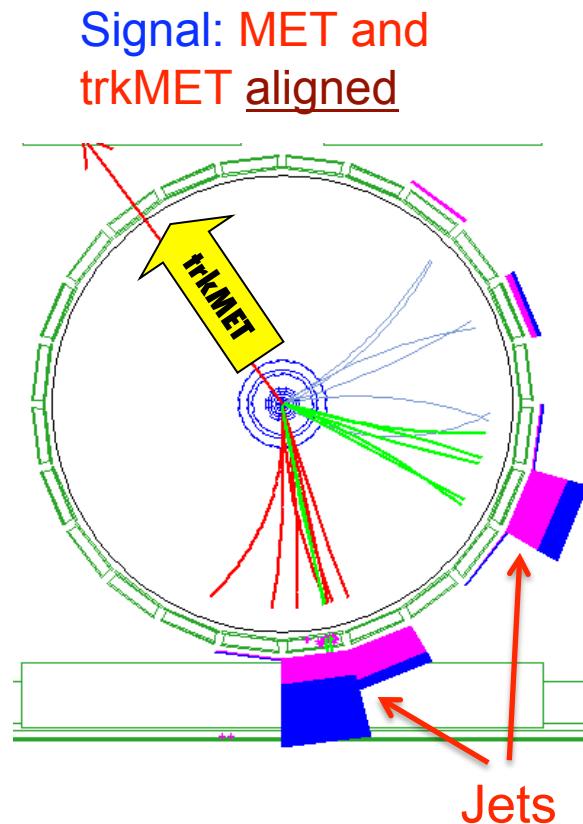
# Example of Diboson Candidate Event



- $\text{MET}=145 \text{ GeV}$
- $E_T(\text{jet1})=103 \text{ GeV}$
- $E_T(\text{jet2})=54 \text{ GeV}$
- $M_{jj}=82 \text{ GeV}/c^2$

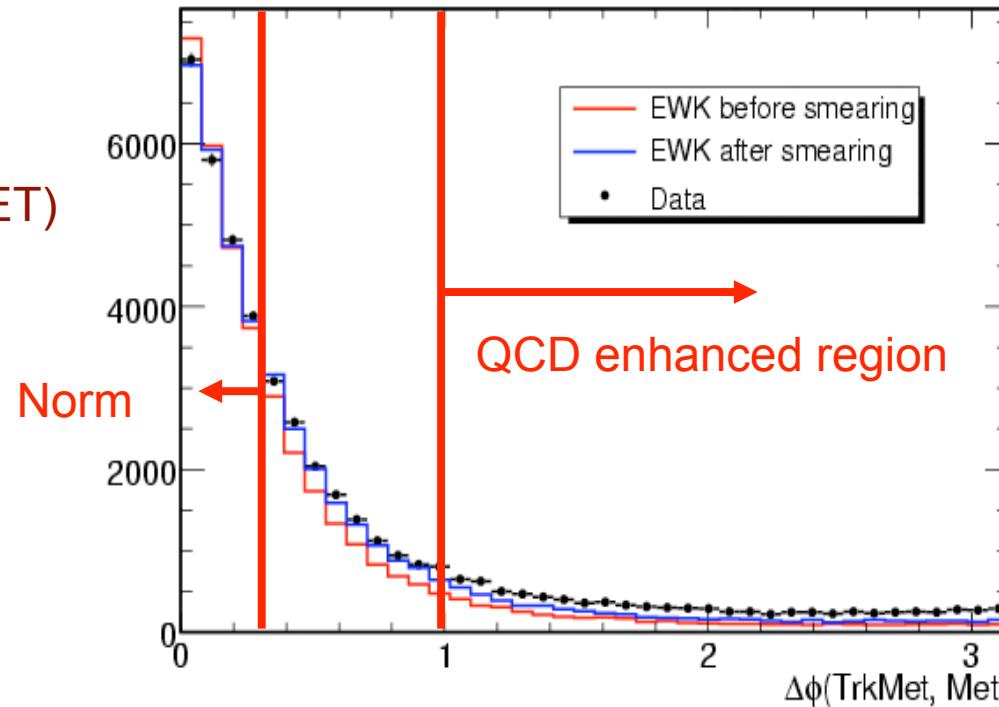
# Modeling Remaining QCD Background

- Two nearly independent ways to detect neutrinos
  - MET: energy imbalance in calorimeter (use towers)
  - Track MET (trkMET): momentum imbalance in tracker (use tracks)



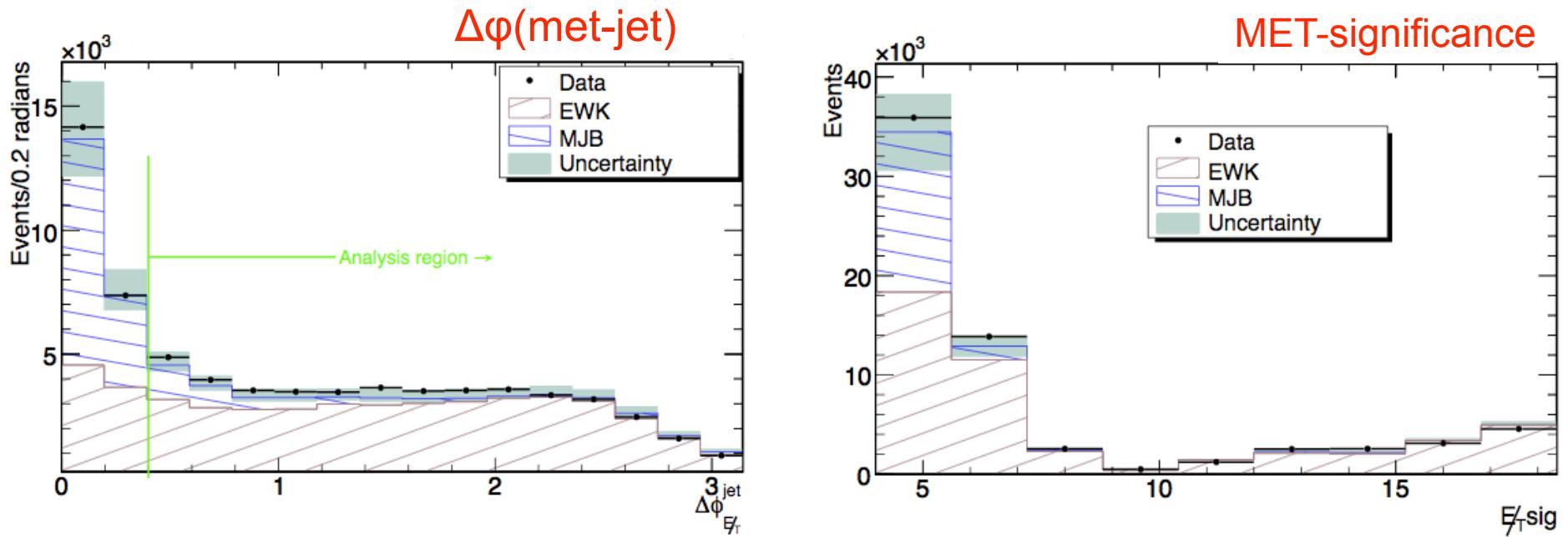
# Modeling Remaining QCD Background

Region of small  $\Delta\phi(\text{trkMET-MET})$   
dominated by EWK events



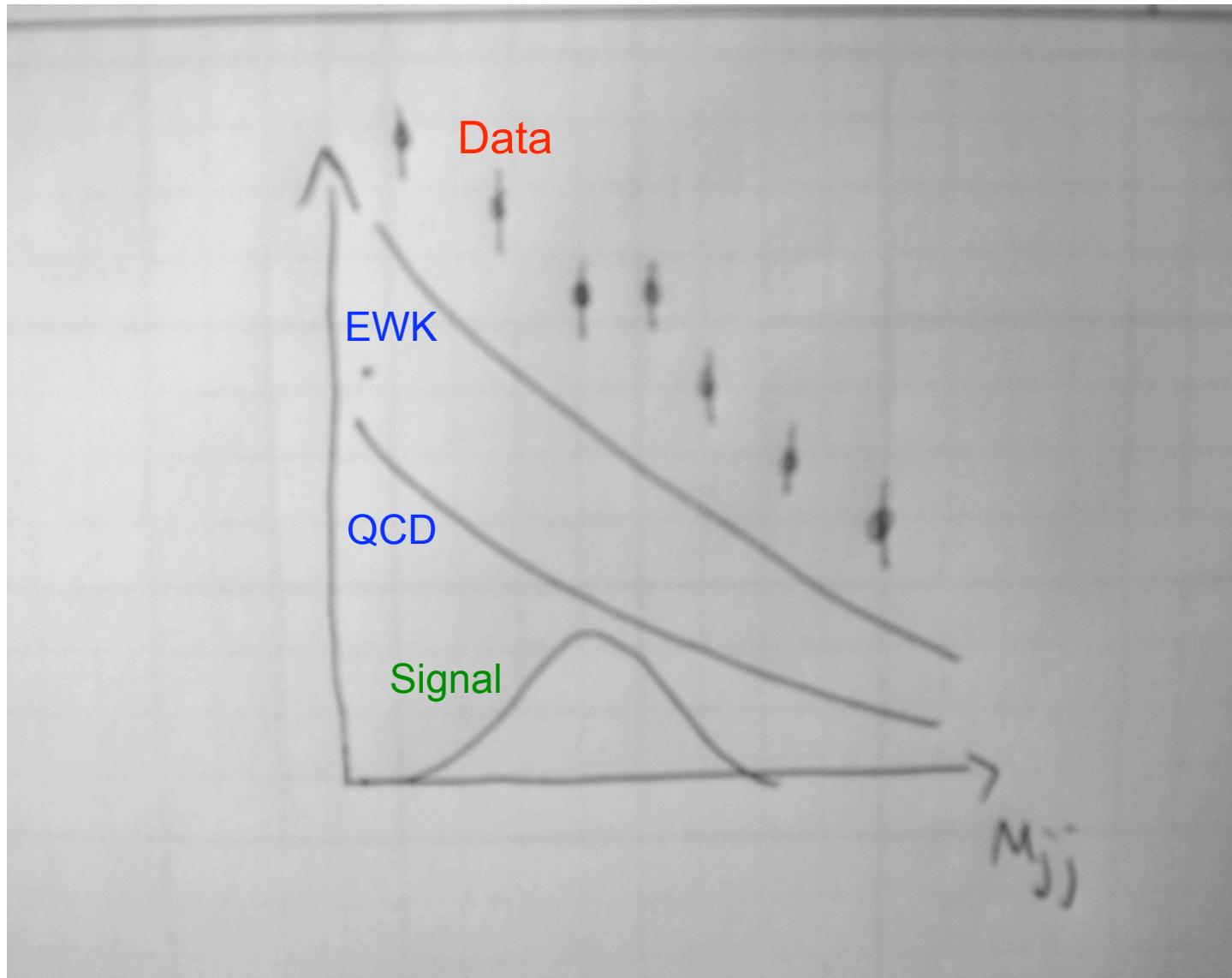
- Subtract EWK predictions from data in  $\Delta\phi_{\text{trkMET-MET}} > 1.0$  region
  - Account for QCD background contribution in peak with dijet MC

# Checking Background Model

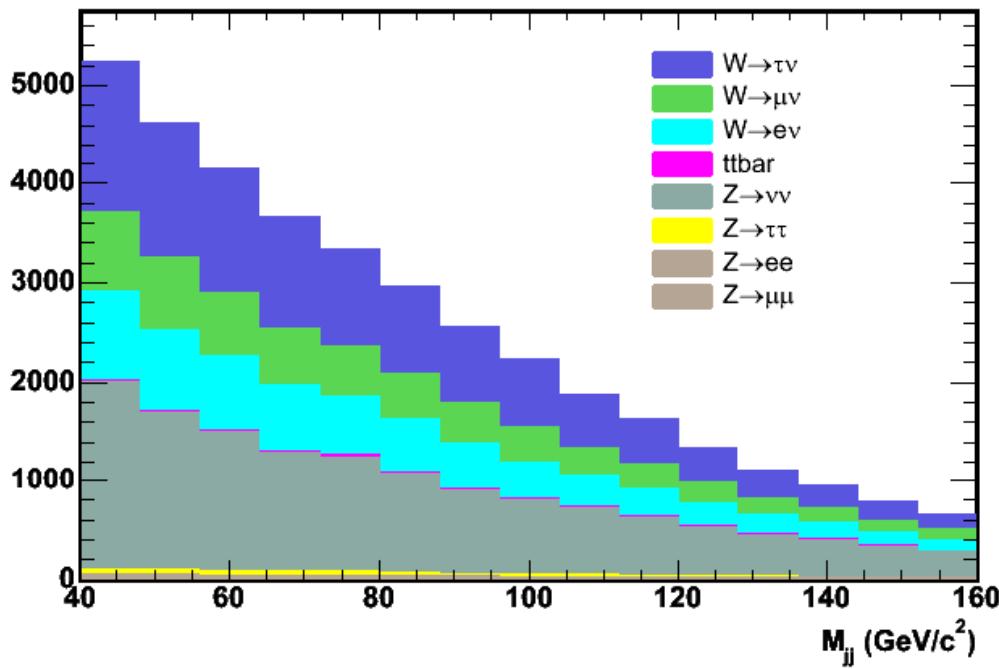


- Data and predictions are in great agreement in distributions sensitive to fake MET
  - MET-significance
  - $\Delta\phi(\text{met-jet})$

# Extracting Diboson Signal: Fit $M_{jj}$ Distribution



# $M_{jj}$ Templates: EWK Background

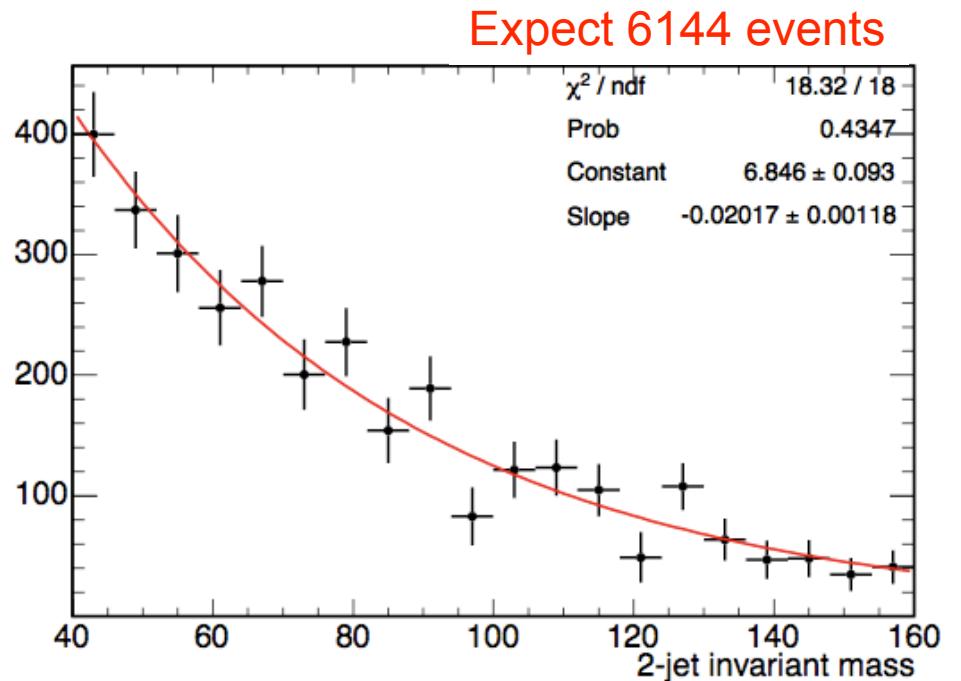
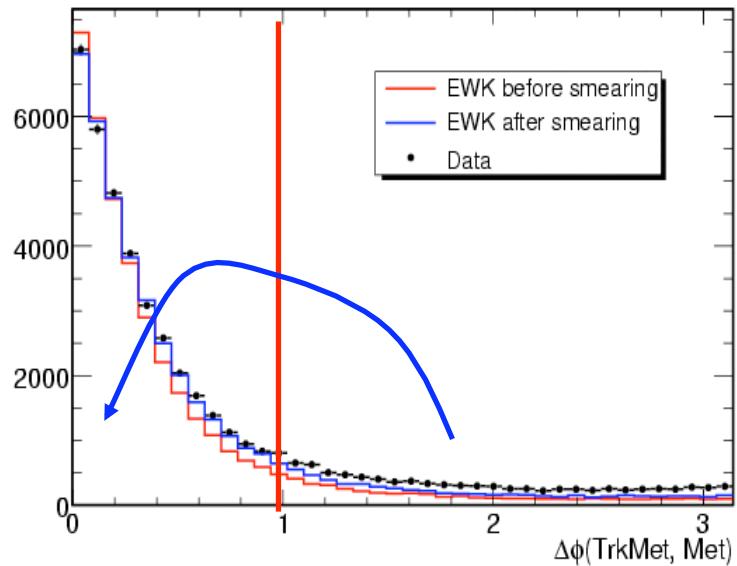


- Shapes taken from MC
- Total number of EWK events is unconstrained in fit

Expect 36,906 EWK events

Process	Expected % of sample
$Z \rightarrow \nu\nu$	<b>28.9</b>
$Z \rightarrow \tau\tau$	1.0
$Z \rightarrow \mu\mu$	0.7
$Z \rightarrow ee$	0.0
$W \rightarrow \tau\nu$	<b>24.1</b>
$W \rightarrow e\nu$	14.4
$W \rightarrow \mu\nu$	12.8
$t\bar{t}$	0.9
Single top	0.5
<b>Total</b>	<b>82.9</b>

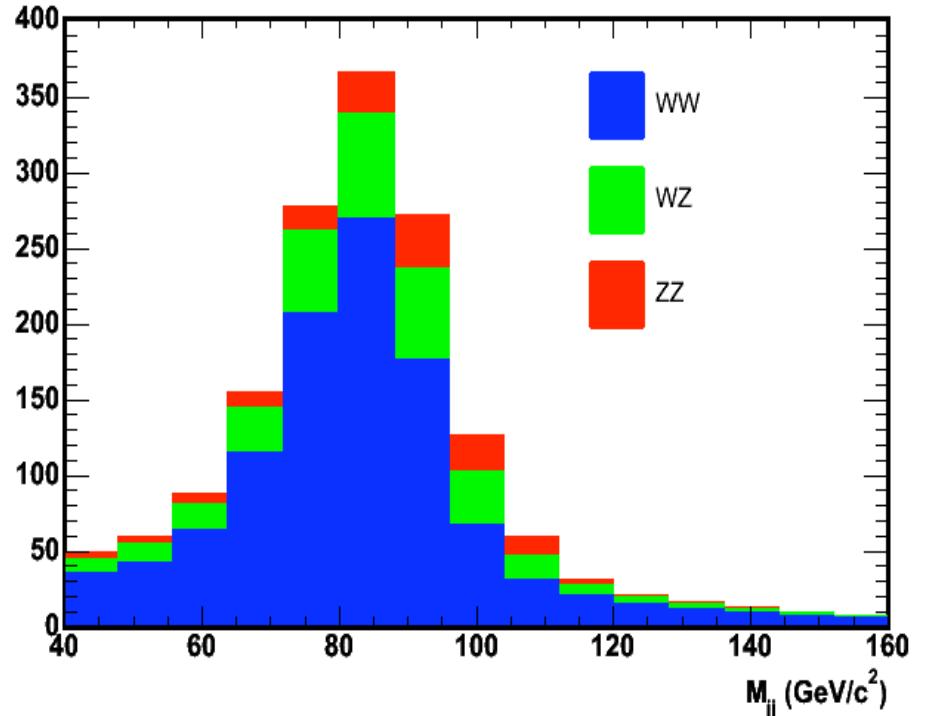
# $M_{jj}$ Templates: QCD Background



- Shape (exponential) & normalization taken from data in the region  $\Delta\phi(\text{trkMET-MET}) > 1.0$  after EWK subtraction
  - Shape & normalization are Gaussian-constrained in  $M_{jj}$  fit
  - Uncertainties driven by extrapolation into  $\Delta\phi(\text{trkMET-MET}) < 1.0$  region

# $M_{jj}$ Templates: Diboson Signal

Process	Expected % of sample
WW	2.3
WZ	0.7
ZZ	0.3
<b>Total Signal</b>	<b>3.3</b>
EWK	82.9
QCD	13.8



- Shape from MC parameterized by Gaussian + polynomial
  - Number of signal events is unconstrained in fit
  - Jet energy scale has a Gaussian constraint in fit
    - Gaussian width depends linearly on JES

# Systematics

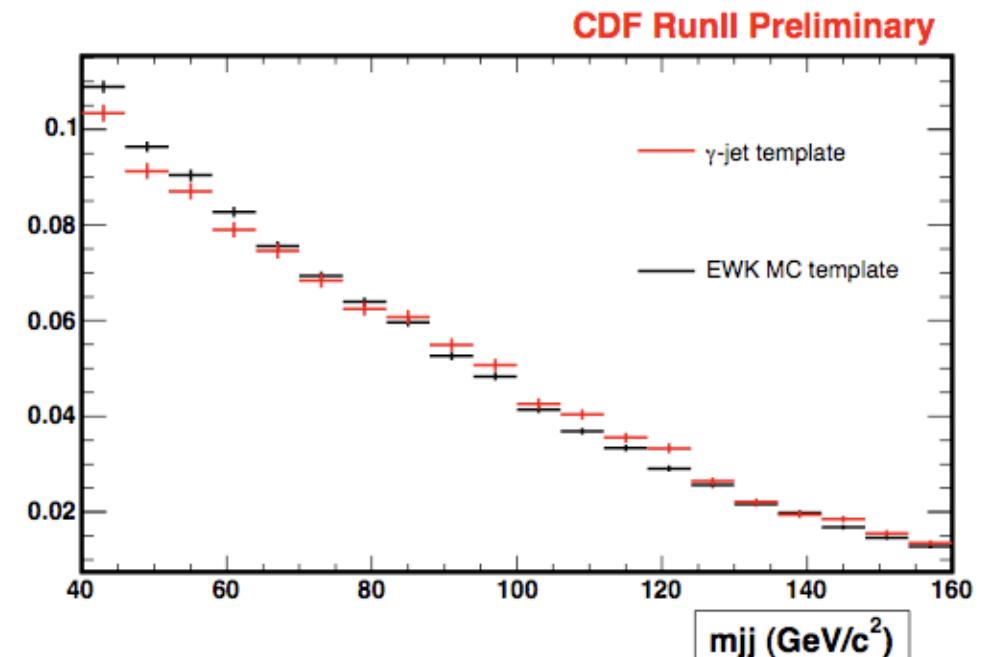
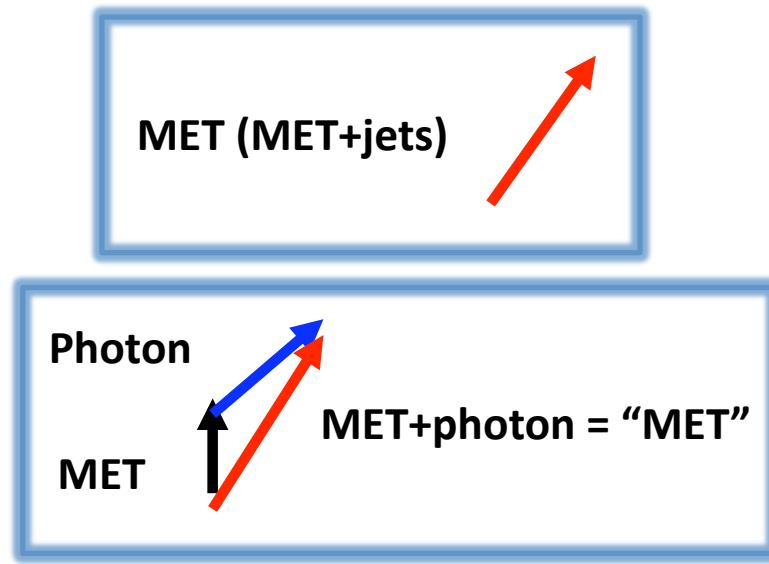
Signal Extraction	% uncertainty
EWK shape	7.7
Resolution	5.6
<b>TOTAL EXTRACTION</b>	<b>9.5</b>
Acceptance	% uncertainty
JES	8
JER	0.7
Met Model	1
Trigger Efficiency	2.2
ISR/FSR	2.5
PDF	2
<b>TOTAL ACCEPTANCE</b>	<b>9.0</b>
<b>LUMI</b>	<b>6</b>
<b>TOTAL SYSTEMATICS</b>	<b>14.4</b>

- Uncertainties associated with nuisance parameters are folded into fit statistical uncertainty
- Remaining systematic uncertainties on signal extraction
  - EWK shape (next slide)
  - Jet energy resolution (JER)
    - Smear signal template according to JER uncertainty

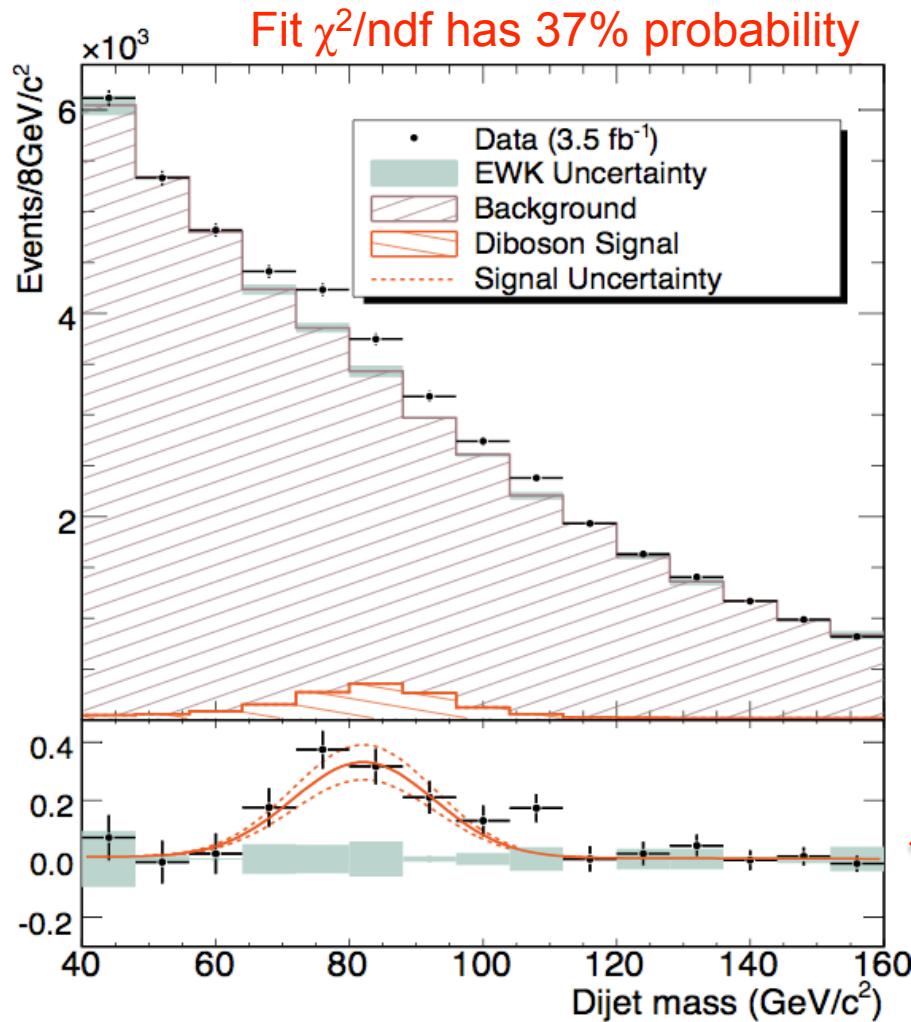
# Systematics on Shape of EWK Background

- Use data  $\gamma+jets$  as alternative template
  - Many uncertainties eliminated
- **Basic idea:** kinematics of  $V+jets \approx \gamma+jets$ ,  $V=W,Z$

$$V + jets(data) = \frac{V + jets(MC)}{\gamma + jets(MC)} \times [\gamma + jets(data)]$$



# Diboson Signal: $1516 \pm 239(\text{stat}) \pm 144(\text{syst})$ Events



- **Signal significance:  $5.3\sigma$**
- **JES from fit:  $0.985 \pm 0.015$** 
  - Official CDF uncertainty: 3%

Data-Background  
Signal fit

# Diboson Cross Section

$$\sigma = \frac{N_{WW}(\text{extracted})}{\varepsilon \cdot A \cdot L}$$

- $N_{WW}(\text{extracted})=1516$
- Efficiency,  $\varepsilon$ 
  - Trigger: 96%
  - Cosmics removal: 99%
- Luminosity,  $L$ :  $3,450 \text{ pb}^{-1}$
- Acceptance is weighted by WW, WZ, ZZ cross sections
- **Cross section**
  - Measured:  $18.0 \pm 2.8(\text{stat}) \pm 2.4(\text{syst}) \pm 1.1(\text{lumi}) \text{ pb}$ 
    - One of the most precise measurements
  - NLO theory (MCFM):  $16.8 \pm 0.5 \text{ pb}$

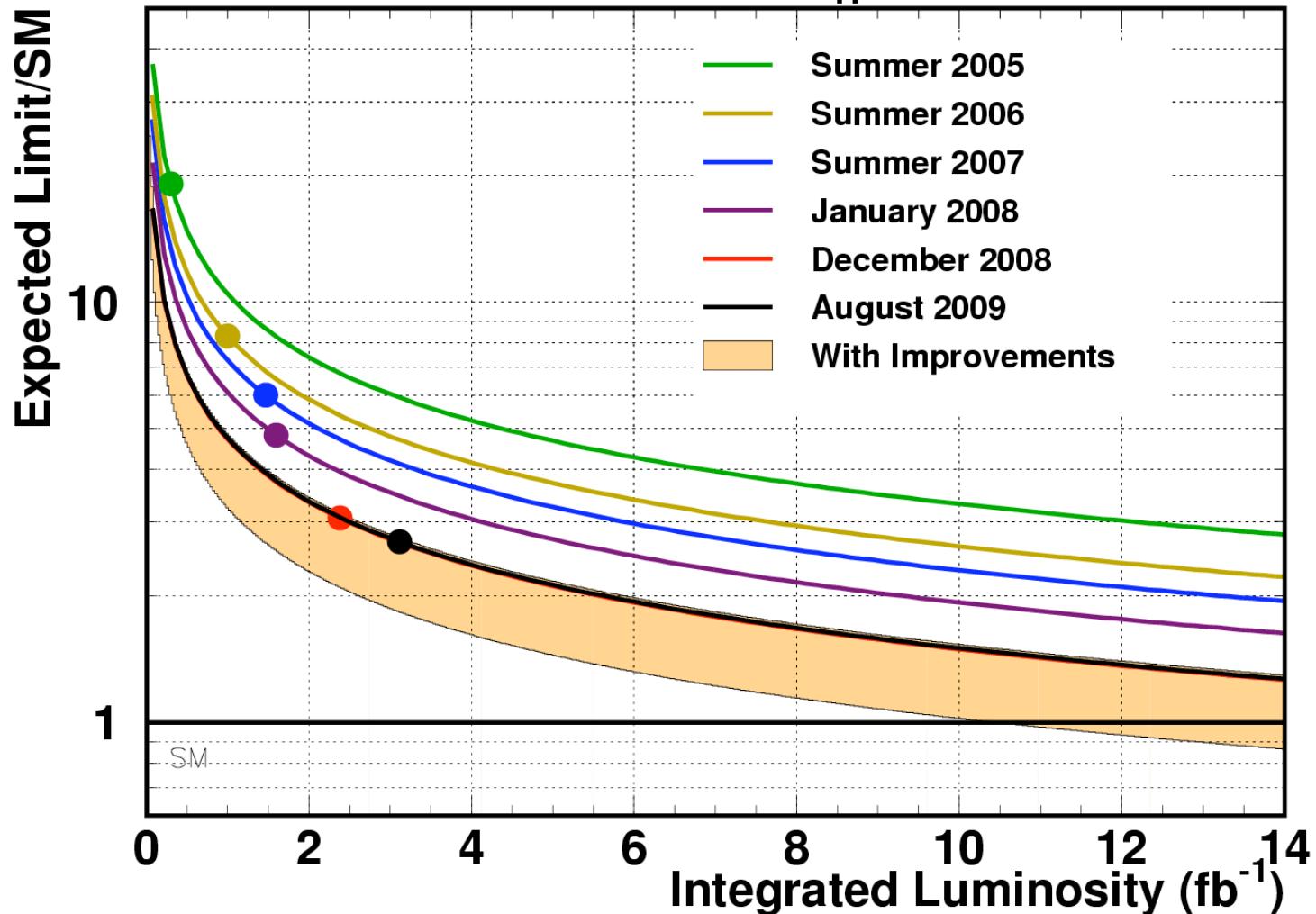
Process	Cross Section, pb	Acceptance, %
WW	11.7	2.48
WZ	3.6	2.64
ZZ	1.5	2.94

# (Do We Need?) New Ideas for Future

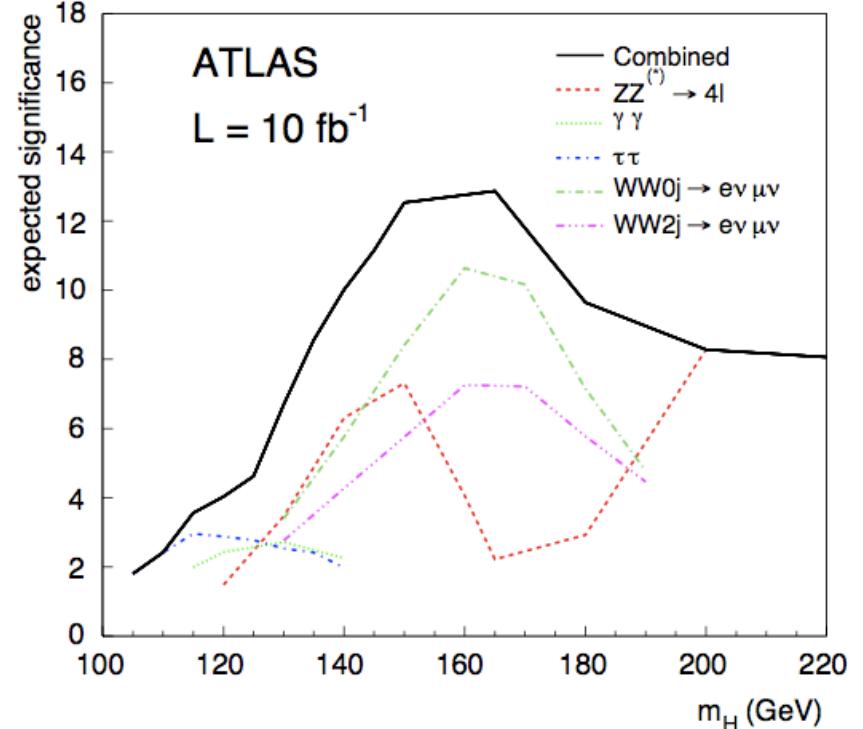
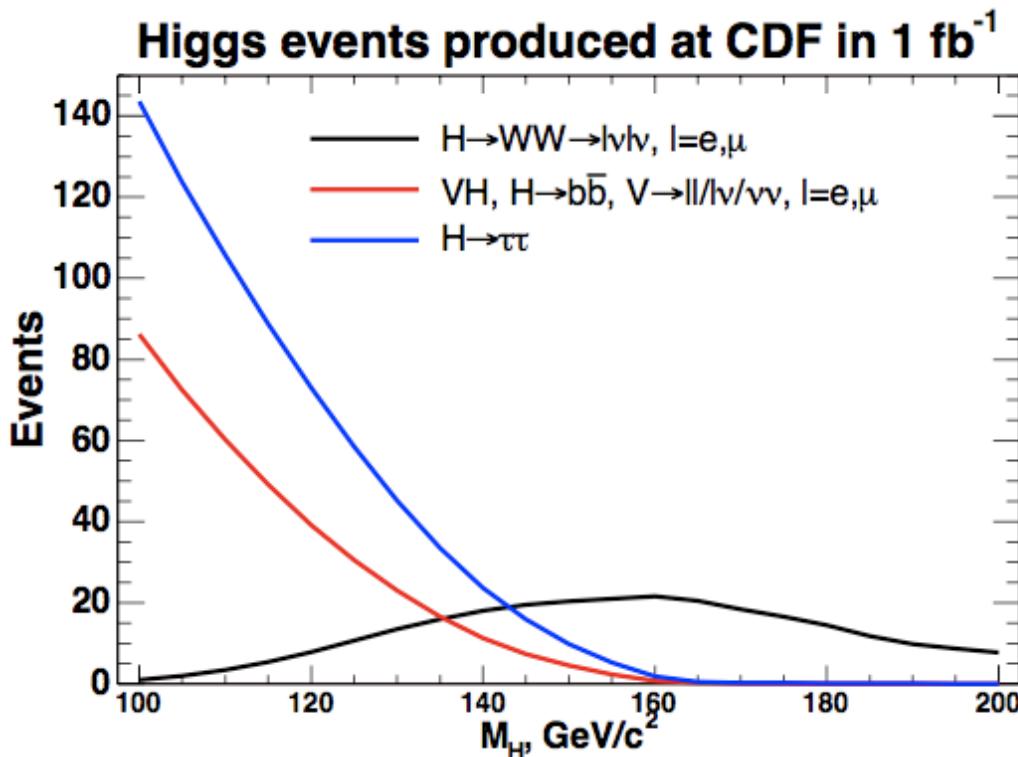


# Are We Stuck??

CDF Run II Preliminary,  $m_H=115$  GeV



# Why Inclusive $H \rightarrow \tau\tau$ ?

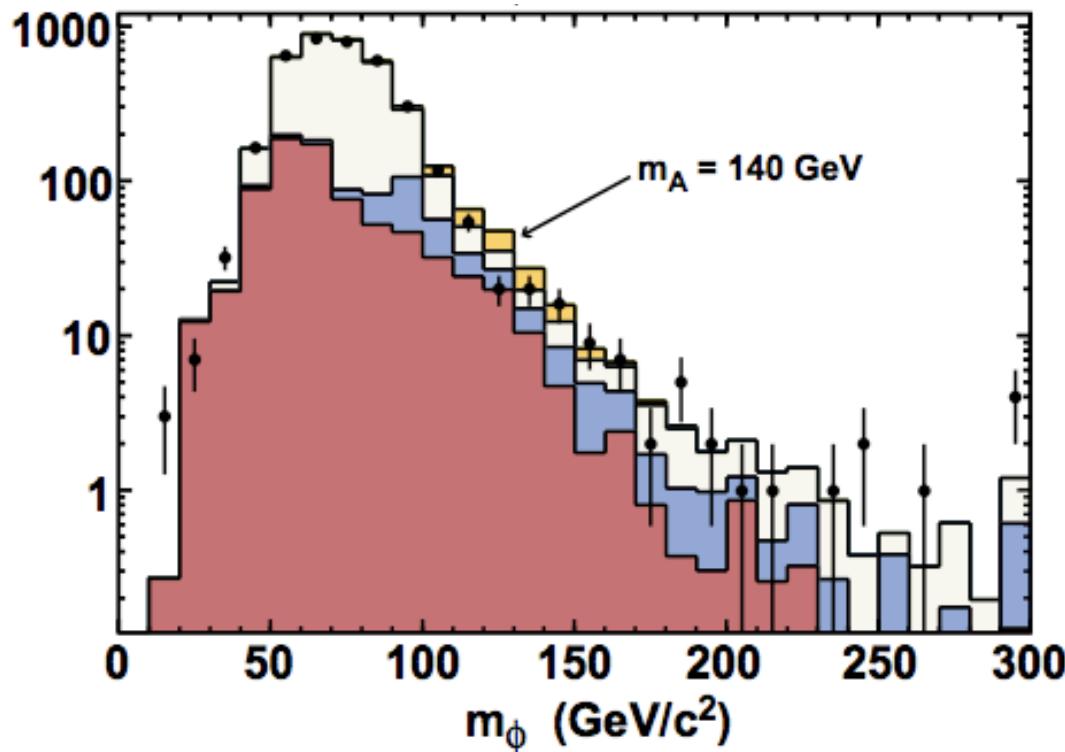


- CDF: more inclusive  $H \rightarrow \tau\tau$  events than  $WH+ZH$  events
  - No “inclusive” analysis; no one has looked into had-had channel
- ATLAS: VBF  $H \rightarrow \tau\tau$  one of primary channels for  $M_H < 130 \text{ GeV}$
- $H/h/A \rightarrow \tau\tau$  primary channel for MSSM Higgs

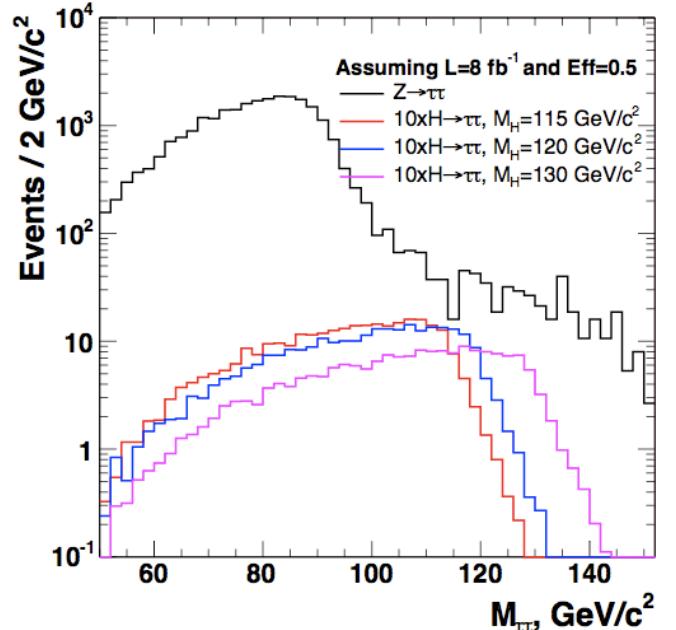
# Challenge: Higgs “Sits” on Big Shoulder of Z-peak

Plot from CDF MSSM Higgs analysis

[arXiv:0906.1014v1](https://arxiv.org/abs/0906.1014v1)

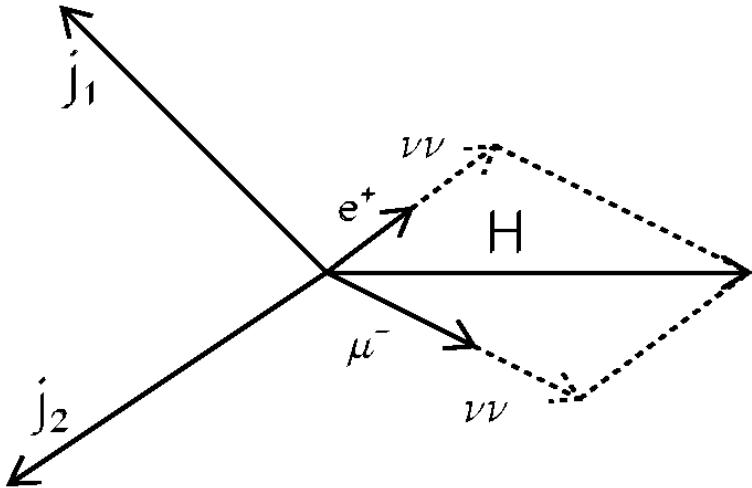


Visible mass at MC “truth” level



- Need an algorithm to precisely reconstruct  $M_{\tau\tau}$  for heavy resonances (like Z & H) and suppress backgrounds

# Reconstructing $M_{\tau\tau}$ : Collinear Approximation



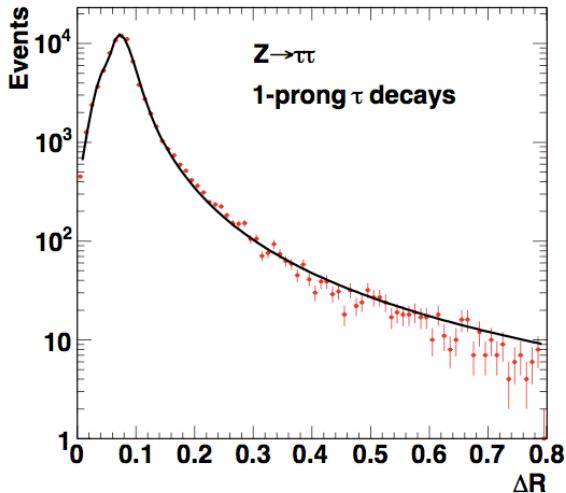
- Basic idea
  - $M_\tau \ll M_Z$  or  $M_H \Rightarrow \tau$ 's heavily boosted
  - Assume  $dR(\nu - \tau_{\text{vis}}) = 0$ 
    - Solve 2 equations with 2 unknowns
    - $\theta_{1,2}$  and  $\varphi_{1,2}$  angles for  $\tau_{\text{vis}1}$  and  $\tau_{\text{vis}2}$

$$E_X = P_{\nu 1} \cdot \cos(\theta_1) \cdot \cos(\varphi_1) + P_{\nu 2} \cdot \cos(\theta_2) \cdot \cos(\varphi_2)$$

$$E_Y = P_{\nu 1} \cdot \cos(\theta_1) \cdot \sin(\varphi_1) + P_{\nu 2} \cdot \cos(\theta_2) \cdot \sin(\varphi_2)$$

- But...
  - Collinear approximation doesn't work for all events
  - Promotes events from low masses to large masses
  - Doesn't help much in rejecting backgrounds with fake taus

# New $M_{\tau\tau}$ Algorithm: Concept



- Basic idea
  - $M_\tau \ll M_Z$  or  $M_H$   $\Rightarrow$   $\tau$ 's are heavily boosted
  - $dR(v-\tau_{vis})$  is very small, but non-zero !!
    - $dR(v-\tau_{vis})$  distribution depends only  $\tau$ -type and  $P(\tau)$

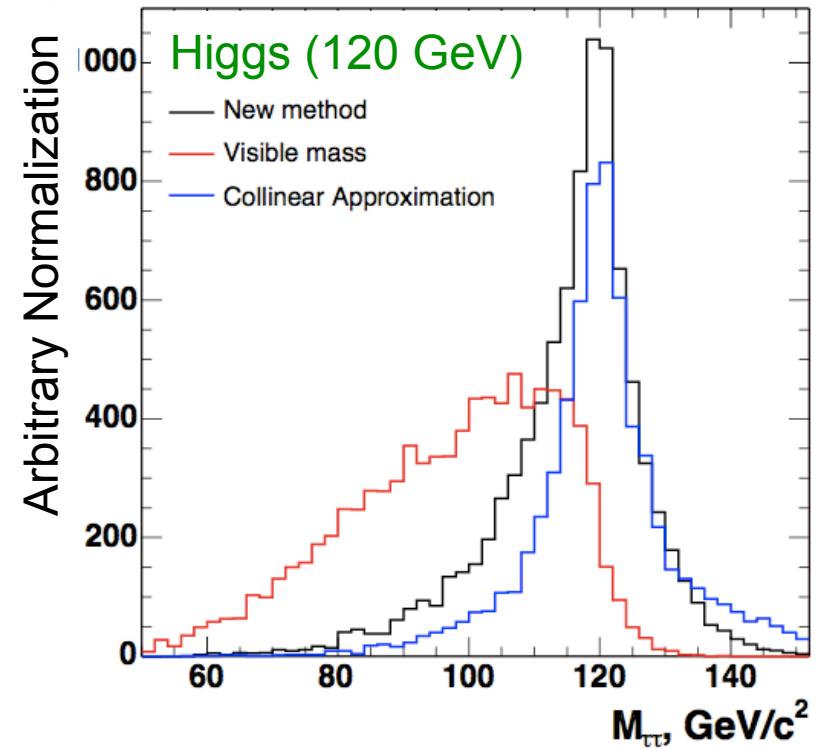
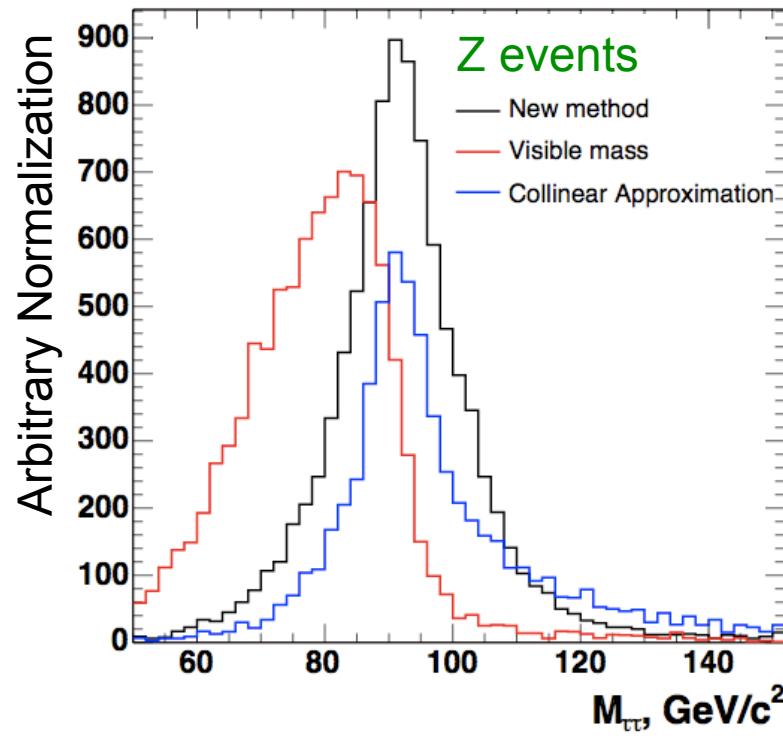
- Create a grid of points in  $[\Delta\theta(v-\tau_{vis}) ; \Delta\phi(v-\tau_{vis})]$  space for each tau
- Solve MET equation for  $P(v1)$  and  $P(v2)$  for each point on the grid

$$E_X = P_{v1} \cdot \cos(\theta_1 + \Delta\theta_1) \cdot \cos(\varphi_1 + \Delta\varphi_1) + P_{v2} \cdot \cos(\theta_2 + \Delta\theta_2) \cdot \cos(\varphi_2 + \Delta\varphi_2)$$

$$E_Y = P_{v1} \cdot \cos(\theta_1 + \Delta\theta_1) \cdot \sin(\varphi_1 + \Delta\varphi_1) + P_{v2} \cdot \cos(\theta_2 + \Delta\theta_2) \cdot \sin(\varphi_2 + \Delta\varphi_2)$$

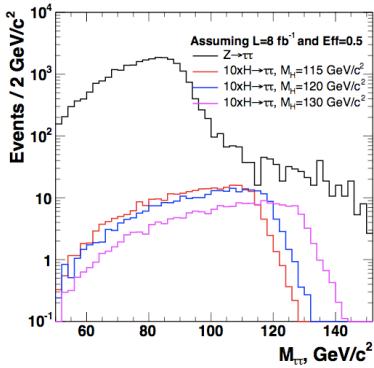
- Construct likelihood: use  $dR(v-\tau_{vis})$ -p.d.f. and impose  $M_\tau$  constraint
- Chose best solution

# Performance of New Algorithm at “Truth” Level

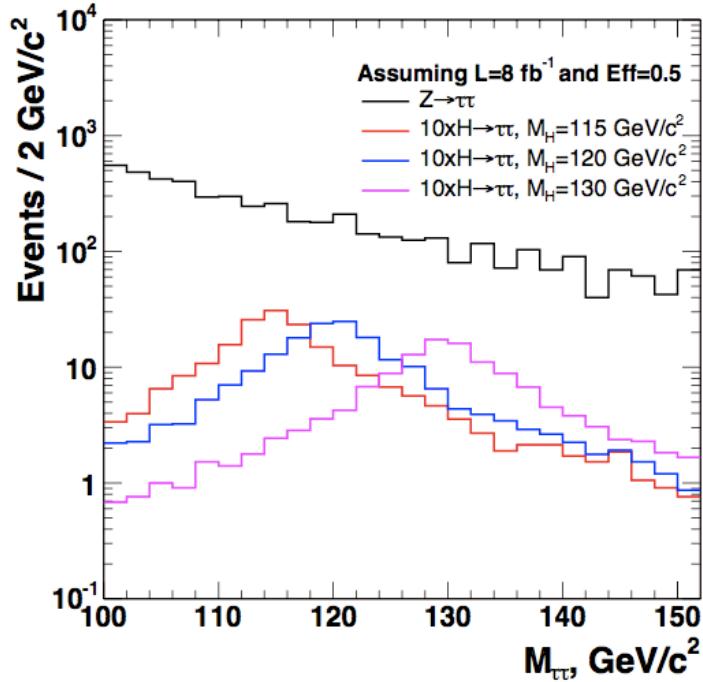


- Visible  $P_T > 15$  GeV and  $|\eta| < 1.0$ , MET  $> 10$  GeV
  - Both calculated at Monte Carlo “truth” level for now
- **New method works for 99% of had-had & had-lep events**
  - Correct peak position; small tails toward large masses
  - Still work in progress (reduce tails, detector effects)

# Three Methods Side-by-Side

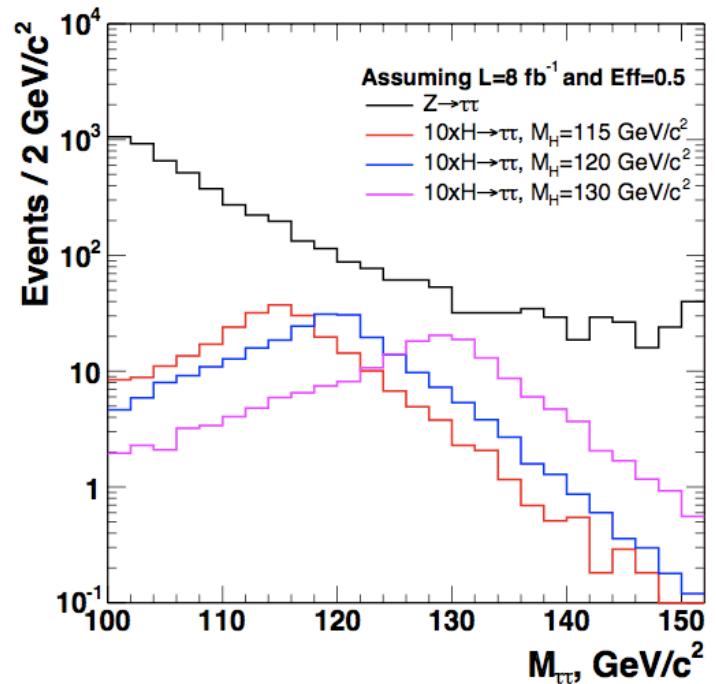


**Visible mass**  
No hope at CDF!



## Collinear Approximation

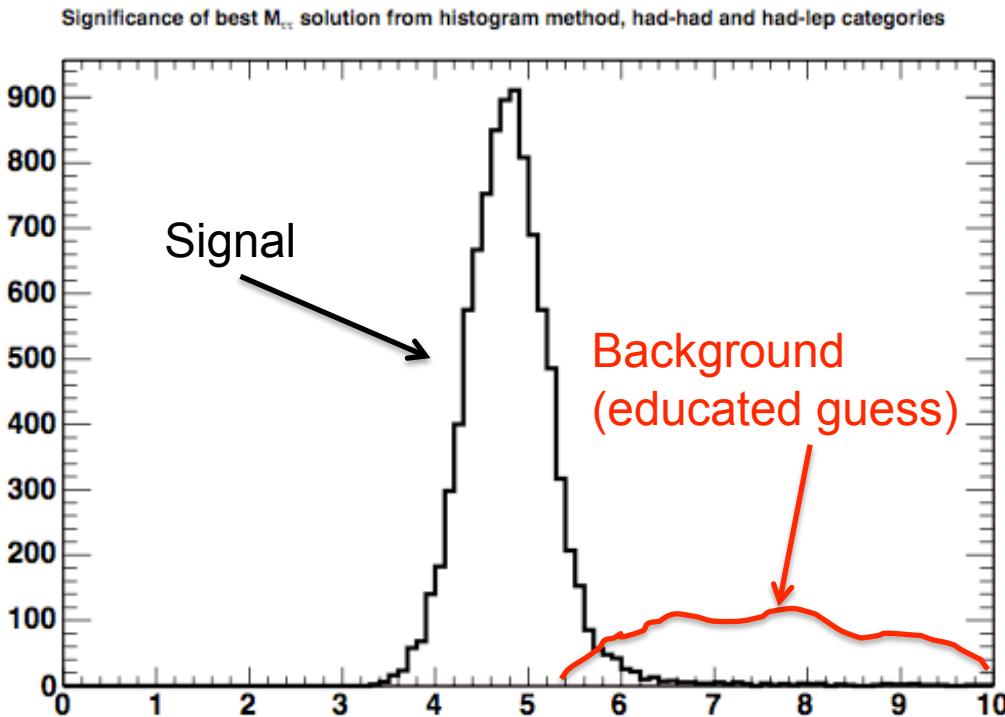
Only for 70%-80% of events  
Huge tail toward large mass



## New Method

Works for 99% of events  
Small tails toward large mass

# Use Fit Significance To Reject Backgrounds



- Same shapes for Z & Higgs
  - events with true taus
- Shape for backgrounds are expected to be different
  - Fake taus
- Difference in signal & background shapes
  - Potential to reject QCD, tt, and W+jet backgrounds

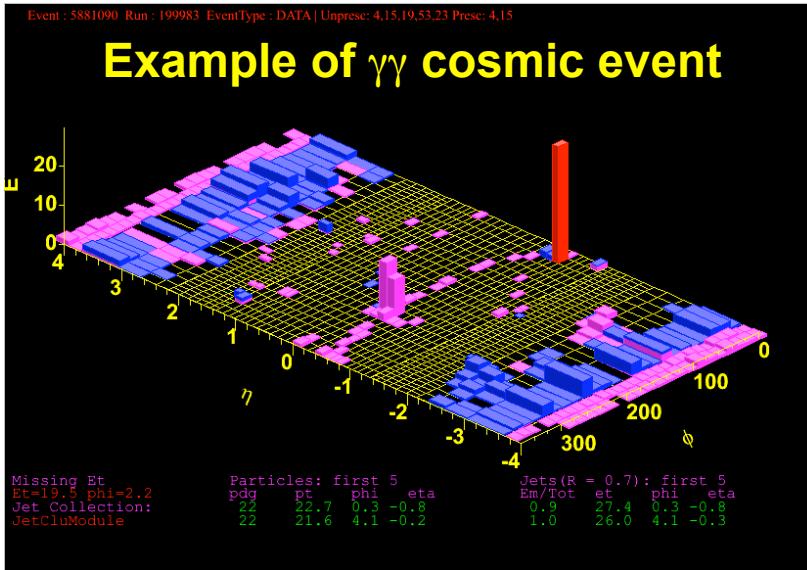
- Significance defined as:
  - $L_{\tau\tau} = -\log_{10}(P_{\tau_1} \cdot P_{\tau_2} \cdot P_{\Delta R 1} \cdot P_{\Delta R 2})$ 
    - $P_{\tau} = \exp(-0.5(m_{\text{rec}} - m_{\tau})^2 / \sigma^2)$  –  $\tau$ -mass resolution
    - $P_{\Delta R}$  –  $\Delta R_{\nu-\tau\text{vis}}$  probability distribution as a function of  $P(\tau)$

# Conclusions

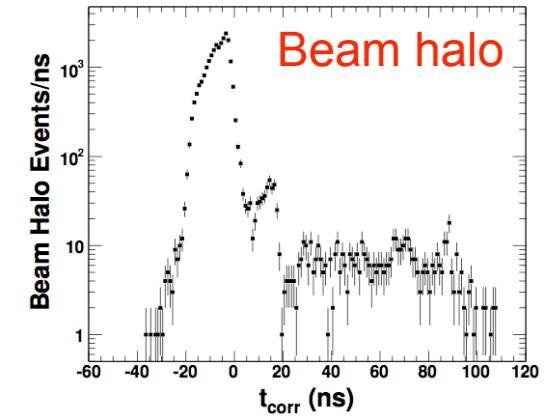
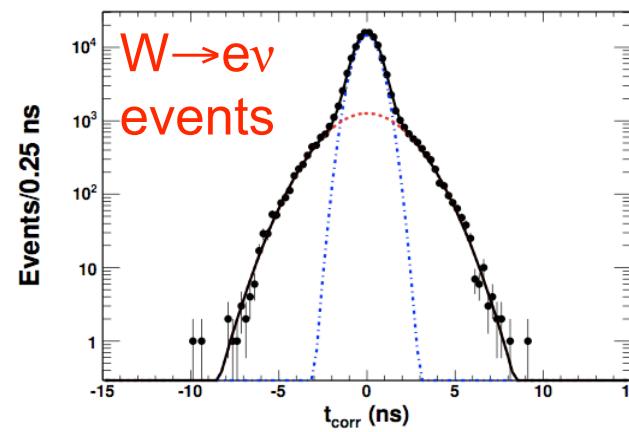
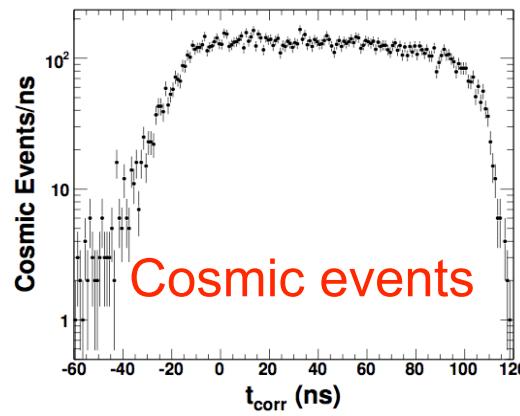
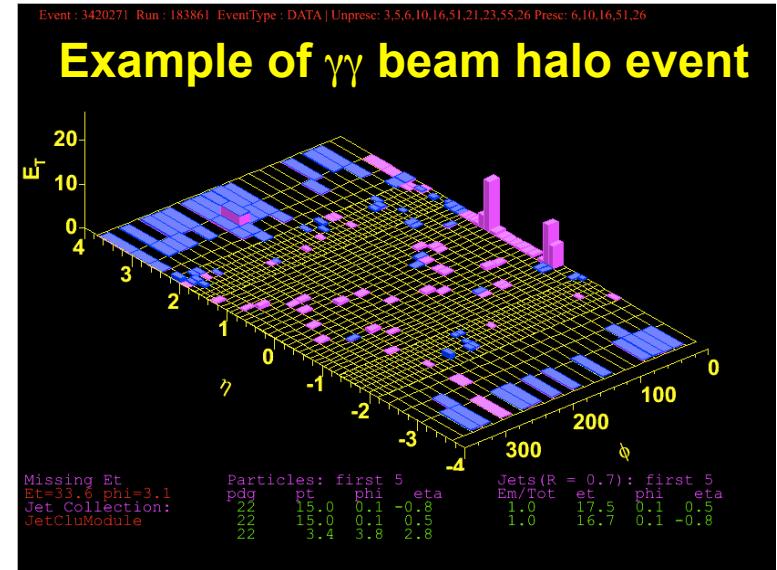
- Search for anomalous  $\gamma\gamma + \text{MET}$  events
  - No signs of new physics  $\Rightarrow$  world's best limit on GMSB
    - PRL 104, 011801 (2010); arXiv:0910.5170 (submitted to PRD)
  - Developed ***Metmodel***
    - Effective method to reject fake MET
    - Used in 3 published analyses; being applied in 4 analyses
- First observation of  $VV \rightarrow jj + \text{MET}$  at Tevatron
  - Milestone in CDF search for low mass Higgs in  $ZH \rightarrow vv + bb$ 
    - PRL 103, 091803 (2009)
  - Developed & tested techniques for Higgs & NP searches in  $jj + \text{MET}$
  - Search for  $VV \rightarrow bb + \text{MET}$  in progress
    - final step before  $H+Z/W \rightarrow bb + \text{MET}$
- Pursuing new ideas for Higgs
  - Inclusive  $H \rightarrow \tau\tau$  with full  $M_H$  reconstruction in all tau decay modes

# Backup Slides for $\gamma\gamma$ +MET

# Backgrounds for $\gamma\gamma$ +MET: Non-Collision Events



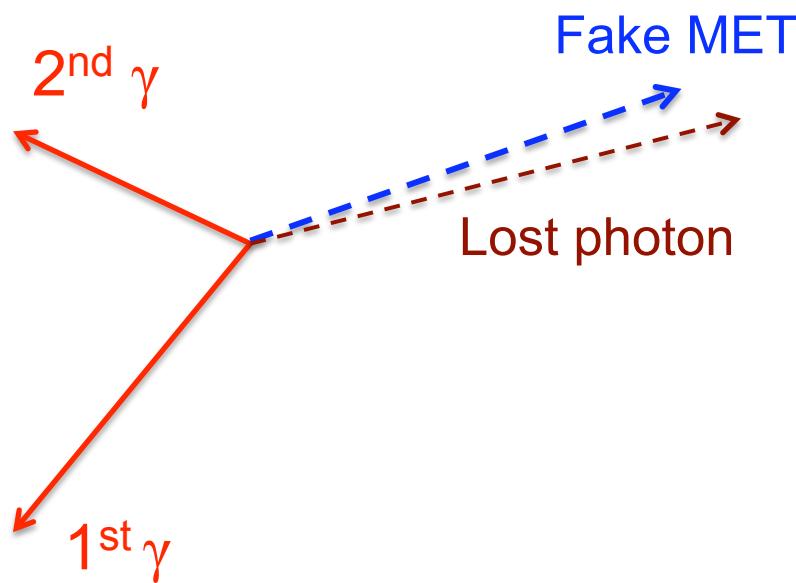
$\eta\text{-}\phi$  view



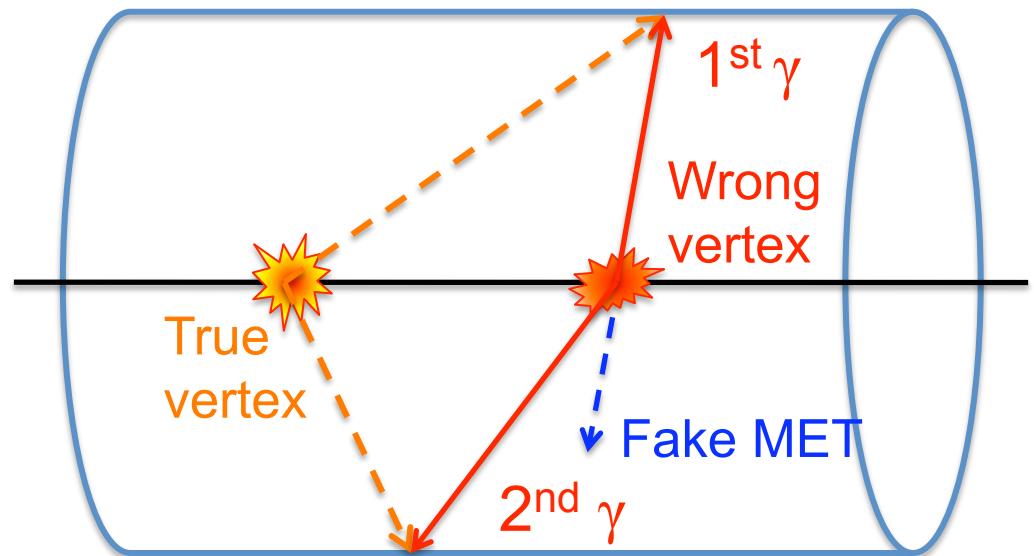
- Use timing information to reject cosmics & beam halo

# Pathological QCD $\gamma\gamma + \text{"MET"}$ Events

“QCD type-2” background



“QCD type-3” background

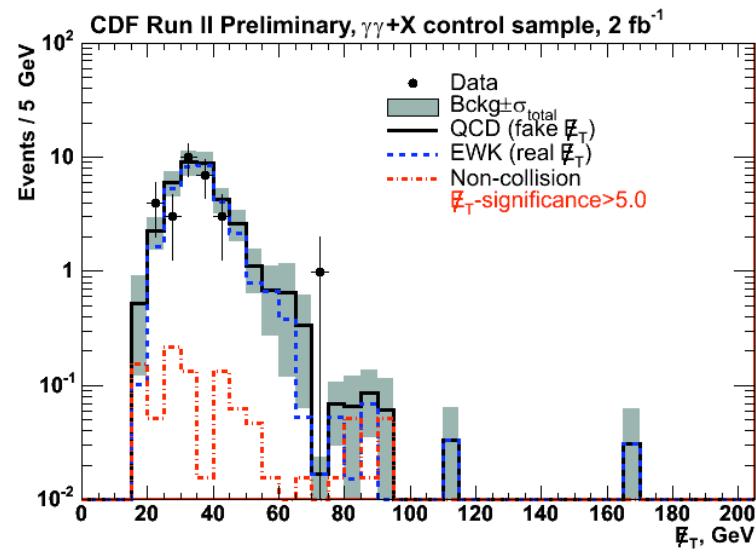
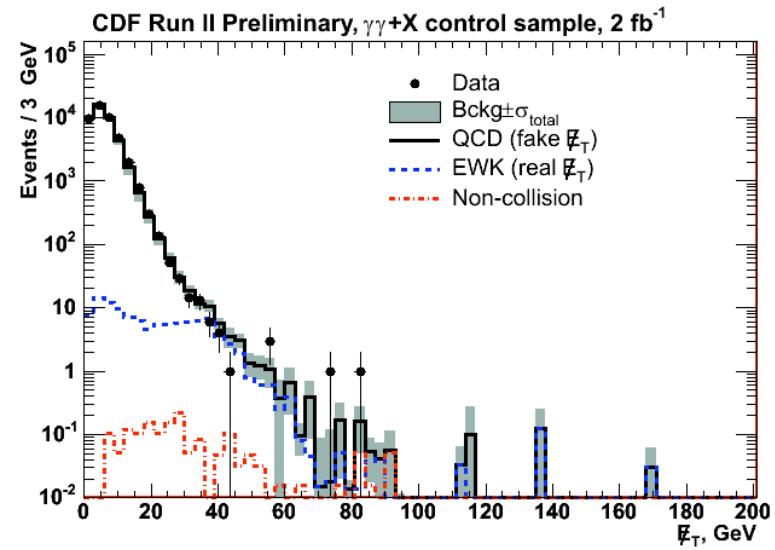
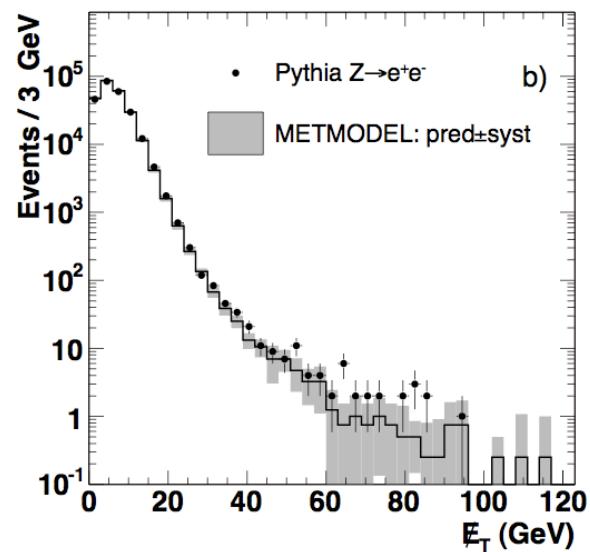
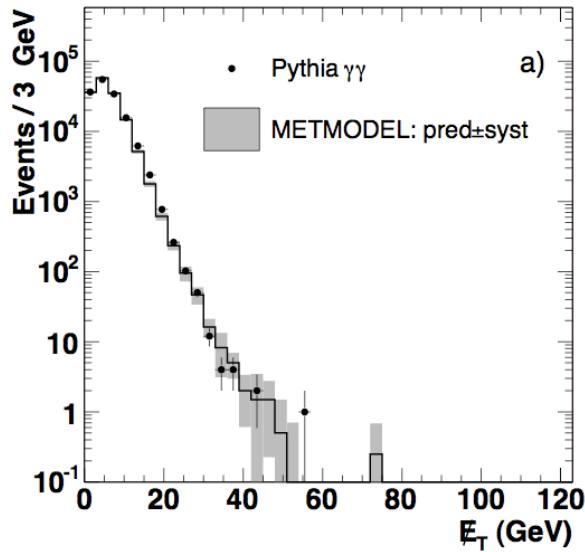


- Photons can be fakes
- MC prediction normalized to data

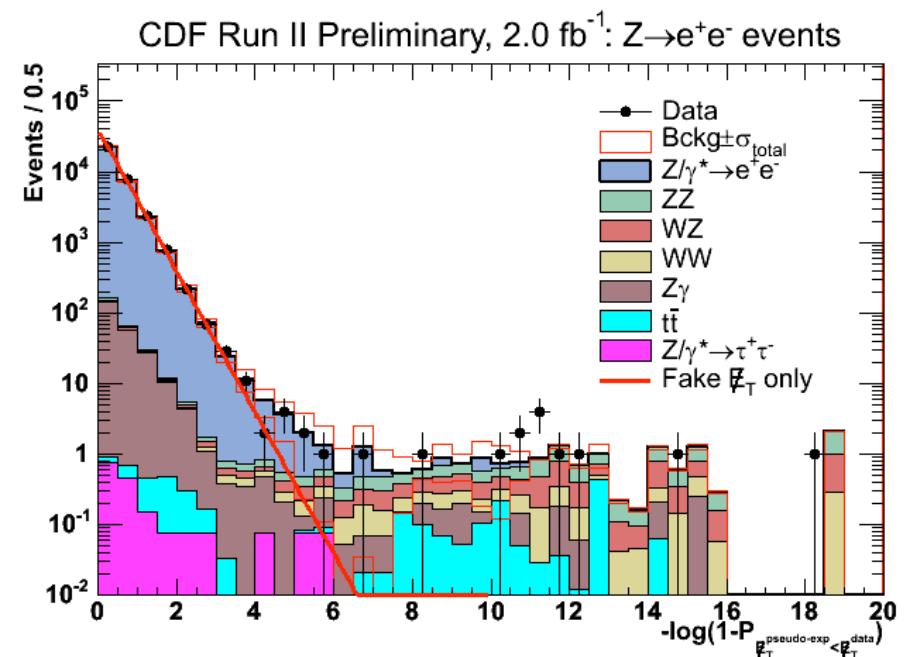
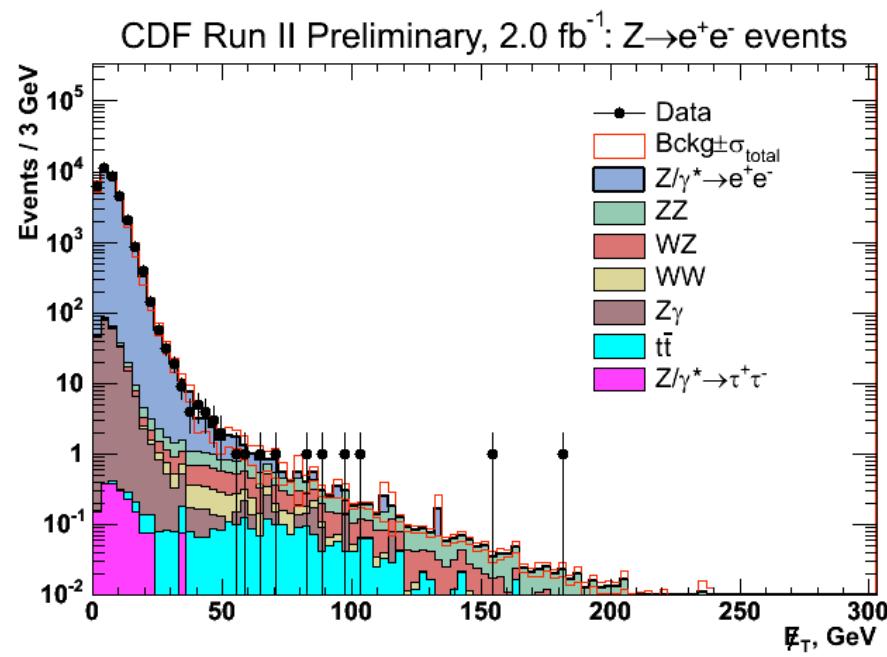
$$MC(\gamma\gamma + \text{lost } \gamma) \times \frac{Data(\gamma\gamma + \gamma)}{MC(\gamma\gamma + \gamma)}$$

- Reconstructed true vertex
  - Re-assign vertex to minimize MET
- Lost true vertex
  - MC prediction normalized to data

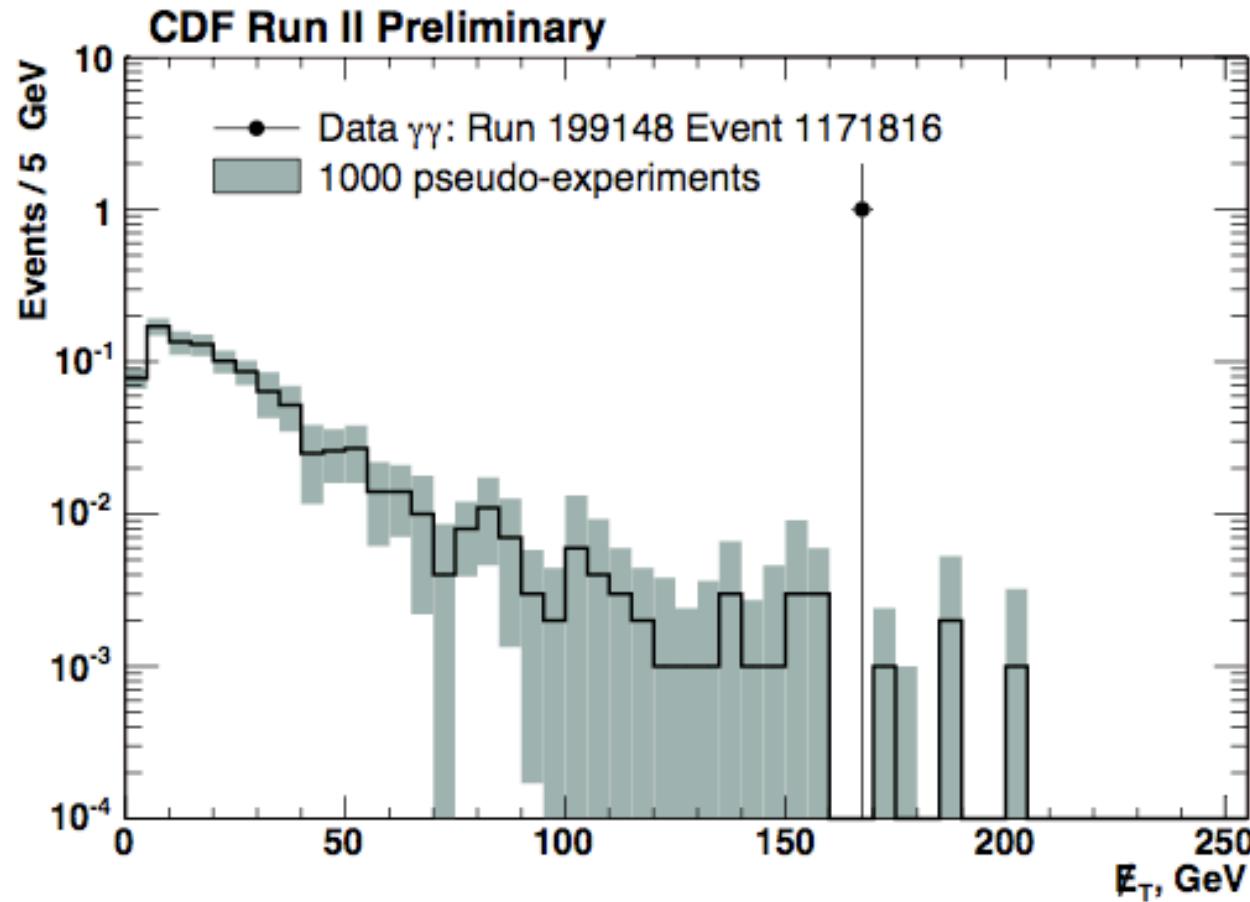
# Tests of METMODEL



# METMODEL in $Z \rightarrow ee$ Events

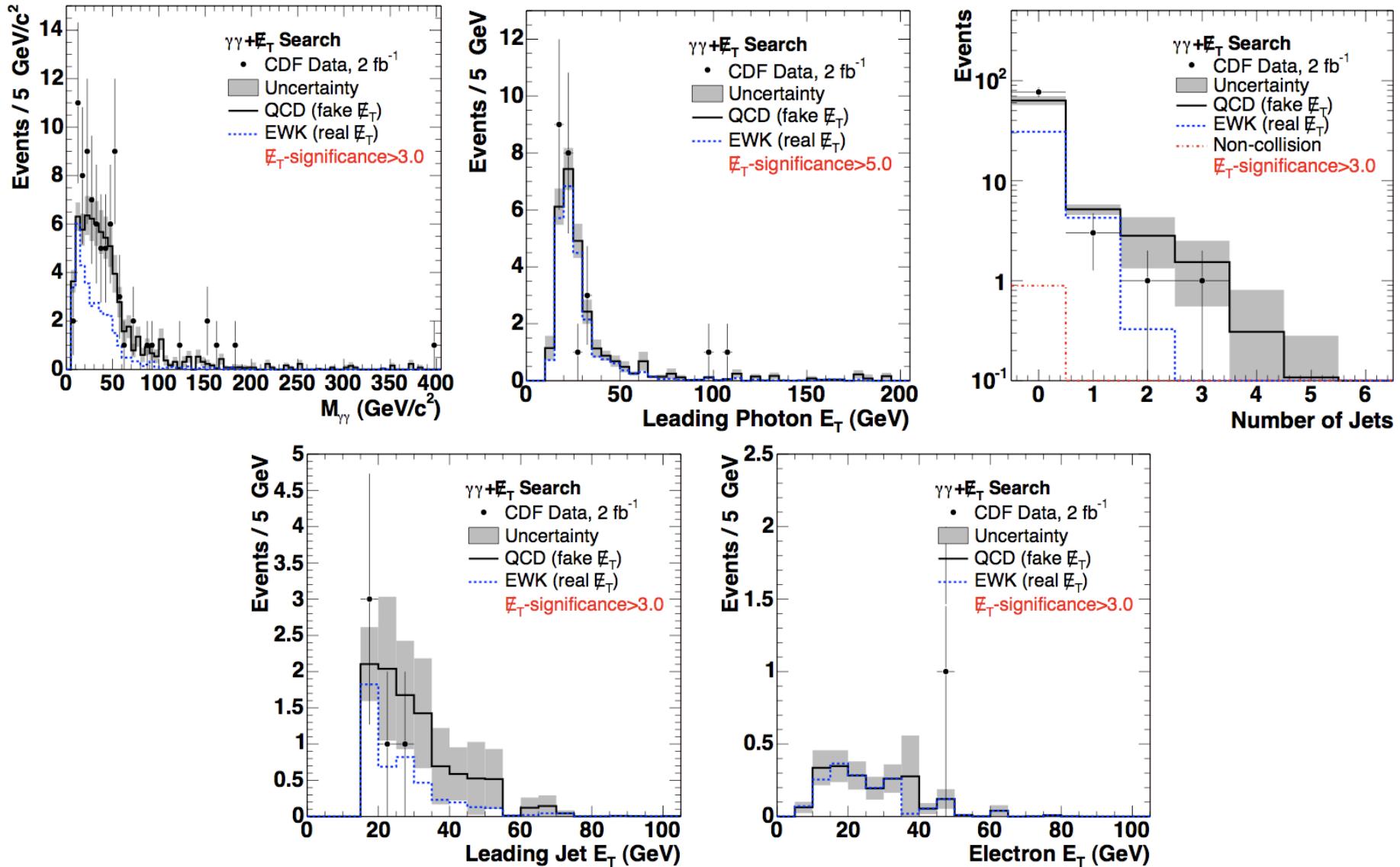


# Largest MET Event in $\gamma\gamma$ +MET Search



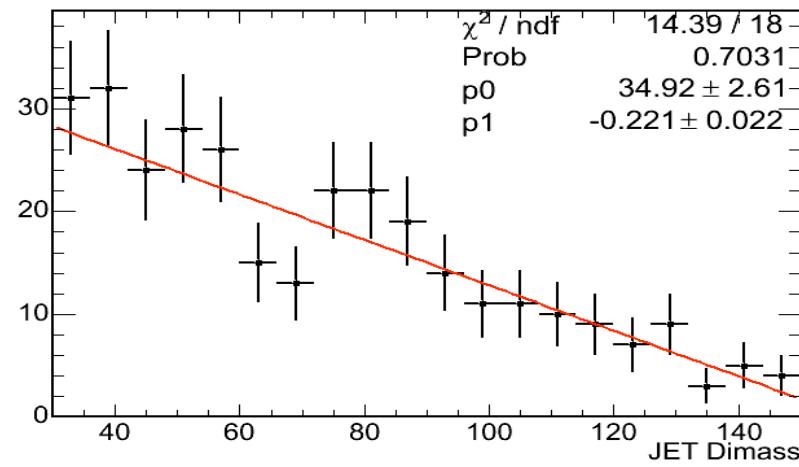
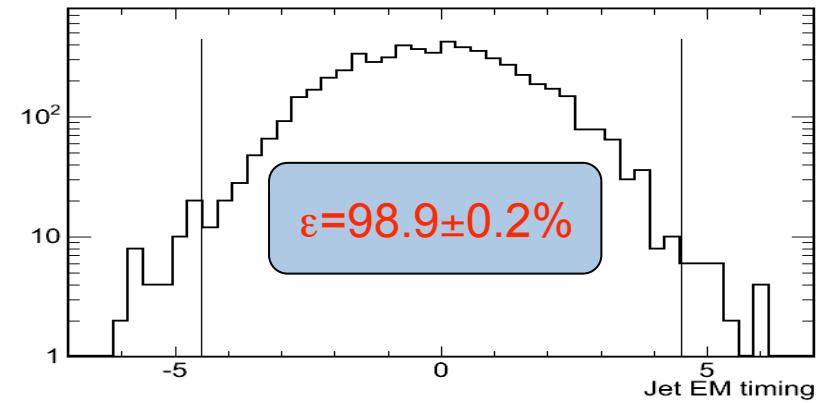
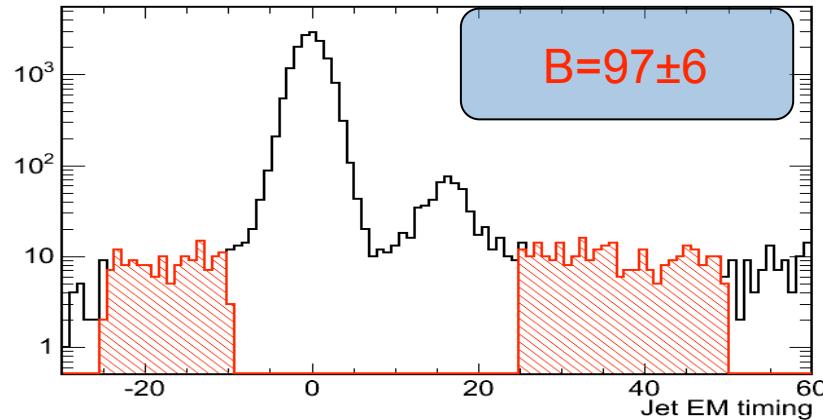
- MET=165.1 GeV
- MET-significance<2.4

# Results for $\gamma\gamma + \text{MET}$ Search



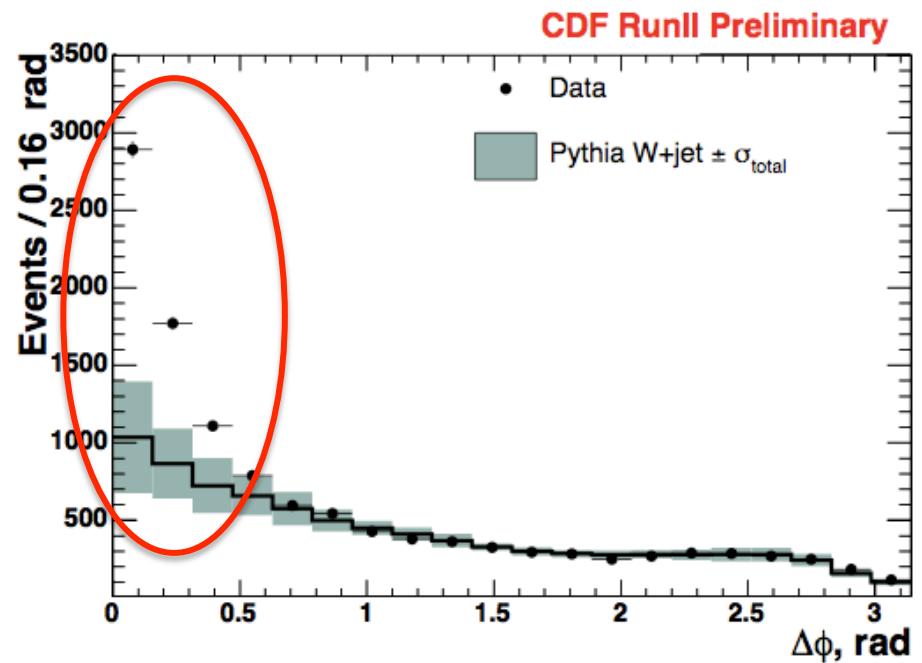
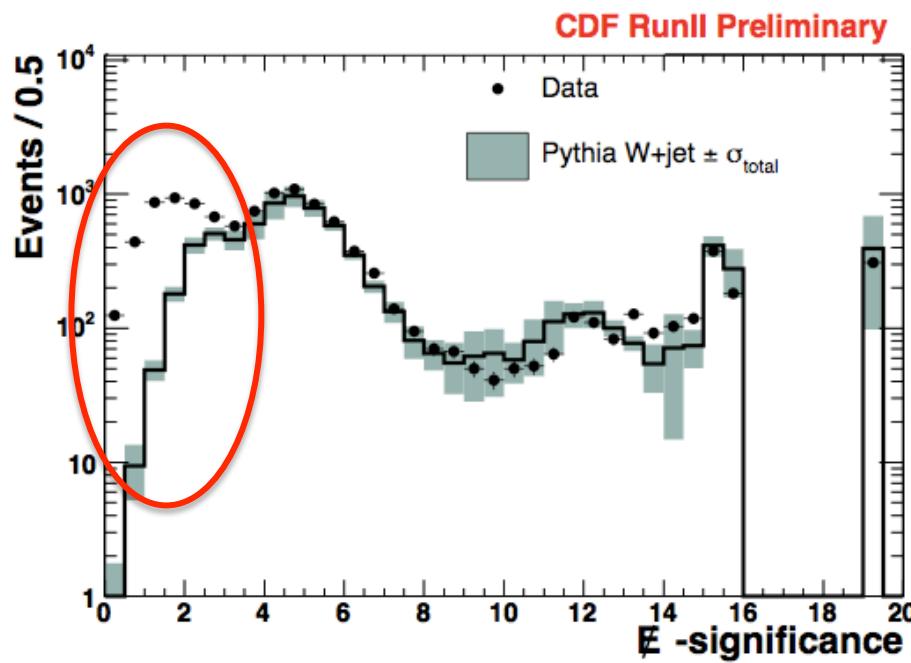
# Backup Slides for MET+JJ

# Cosmic Removal



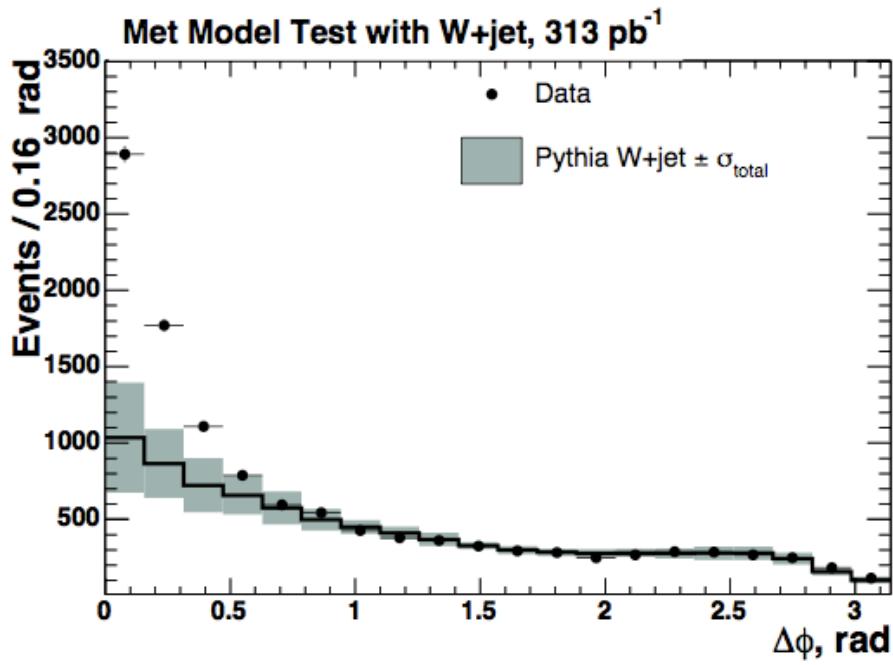
# Validation of Metmodel

- Use  $W(\rightarrow e\nu) + \text{jet}$  data to validate MET-resolution

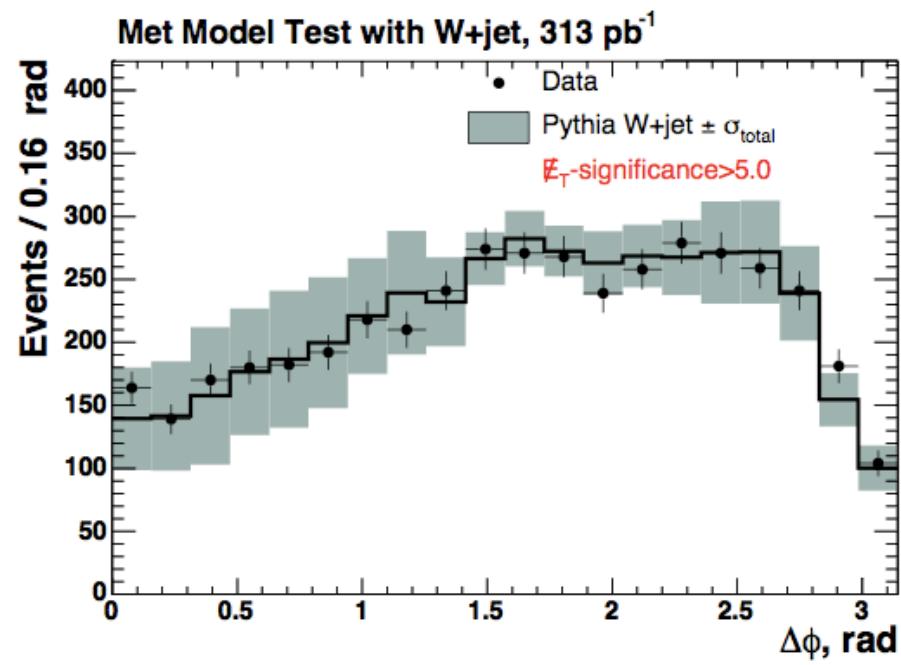


- Regions dominated by events with fake MET
  - Low MET-significance and small  $\Delta\phi(\text{jet-MET})$

# Rejecting Fake MET in W+jet Events: $\Delta\phi_{\text{closest}}$



All events

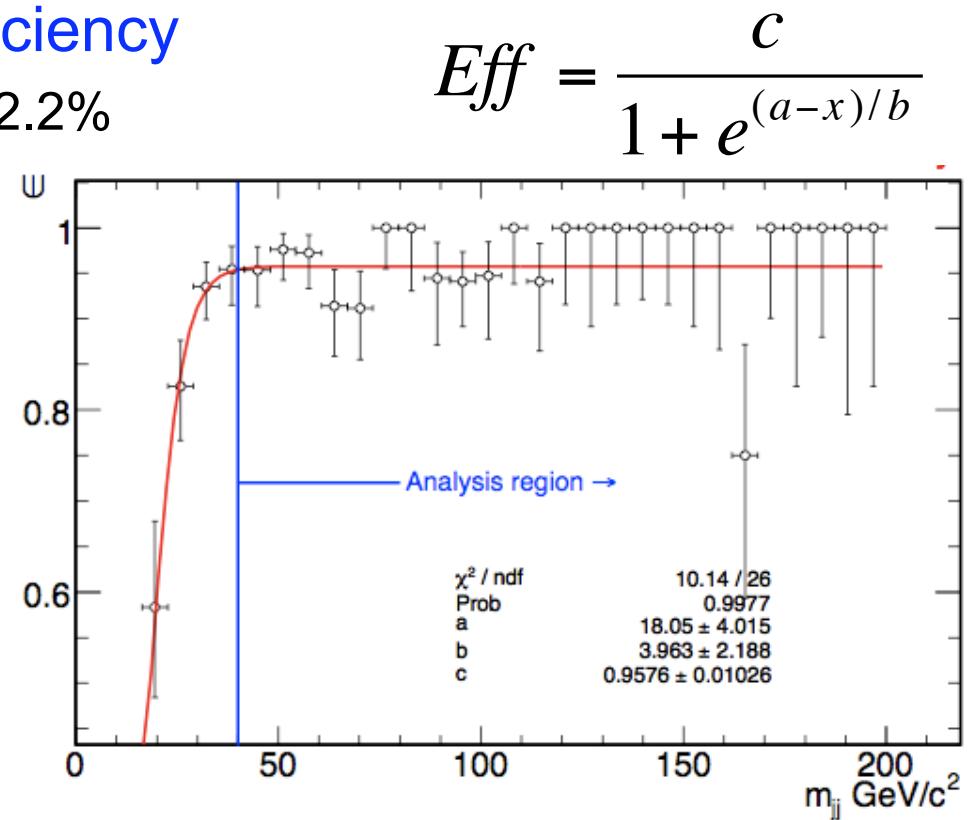
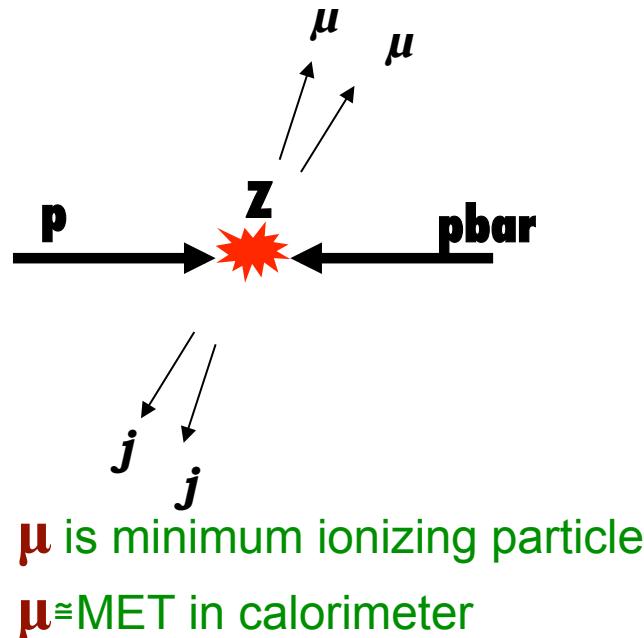


Events after  $\text{MET-sig} > 5$

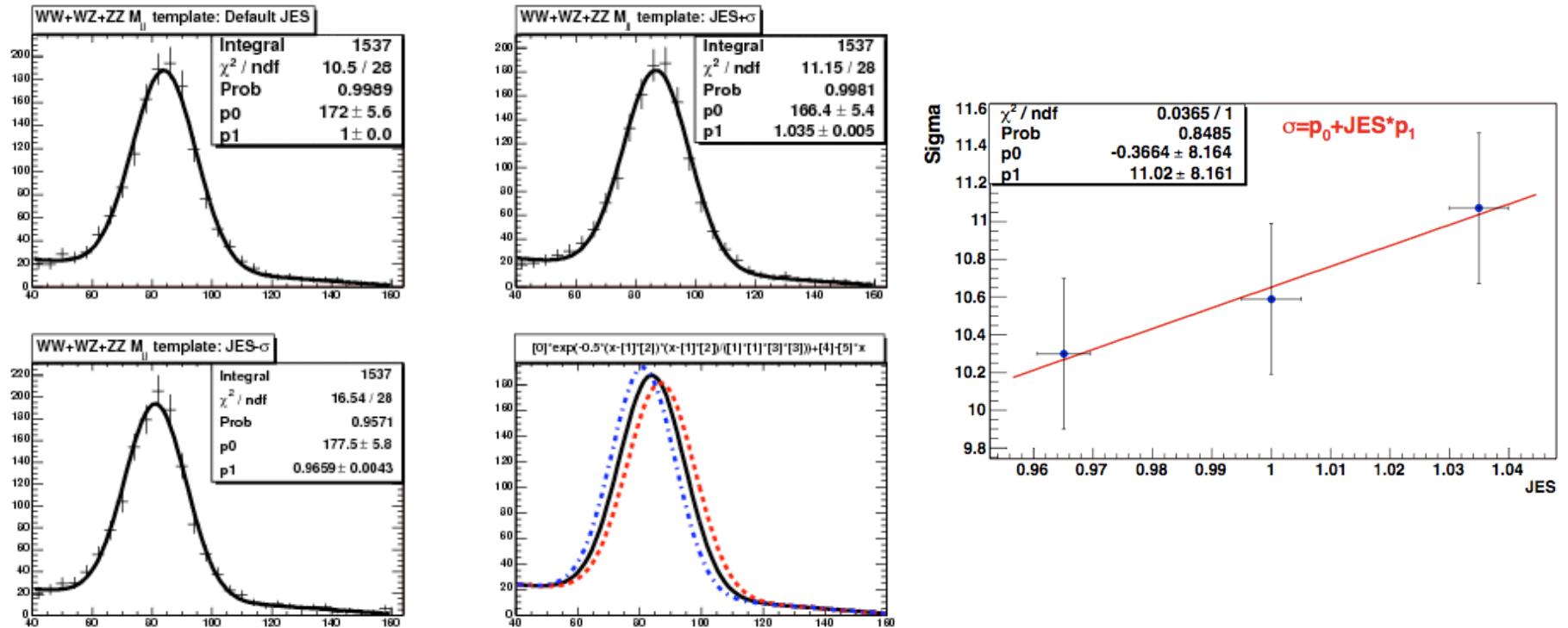
- Left plot: clearly see QCD contribution at small  $\Delta\phi$
- Right plot: QCD is gone if  $\text{MET-sig} > 5$

# Trigger Efficiency

- Use all MET and MET+jets triggers
  - Every bit of extra data counts!
  - Complicates luminosity accounting
- Use  $Z \rightarrow \mu\mu$  events (standard candle) with two jets from high  $P_T$  triggers to find trigger efficiency
  - Integrated efficiency  $96.4\% \pm 2.2\%$

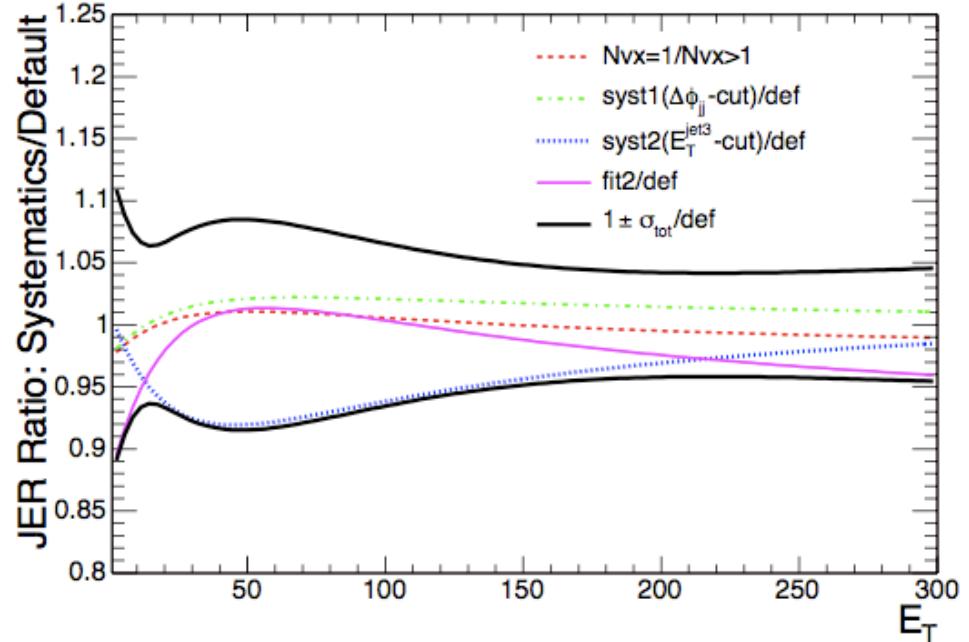
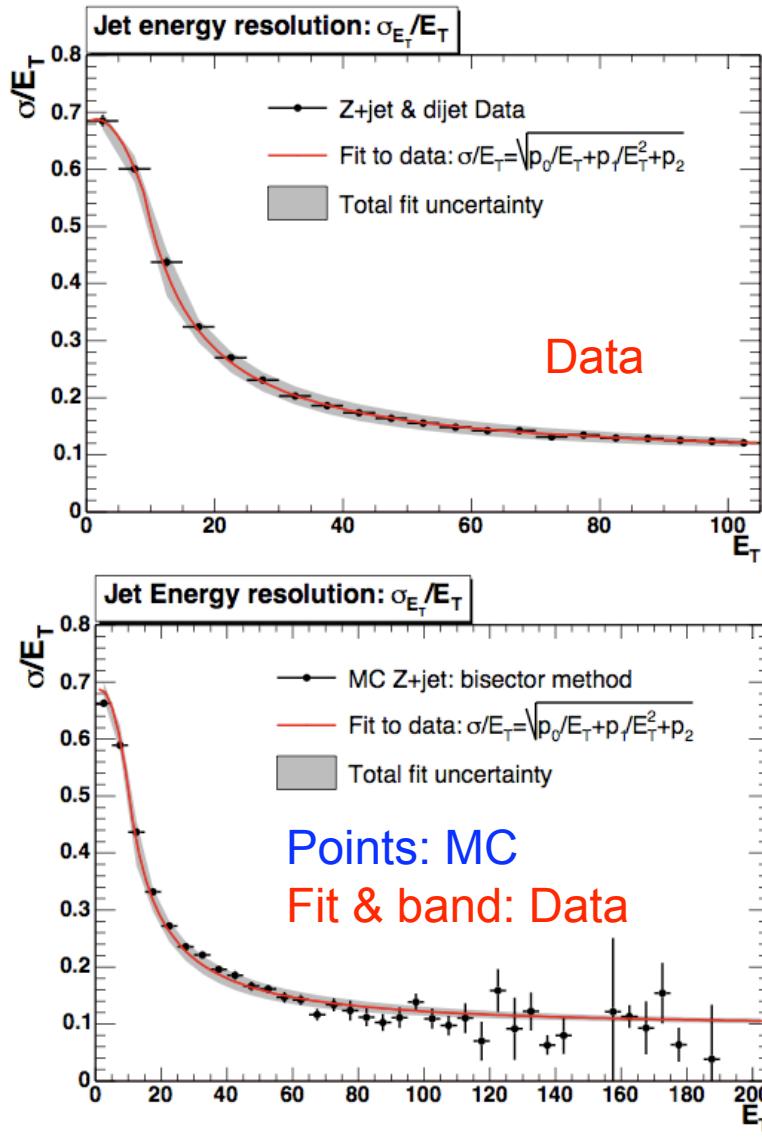


# Signal Template for Final Fit



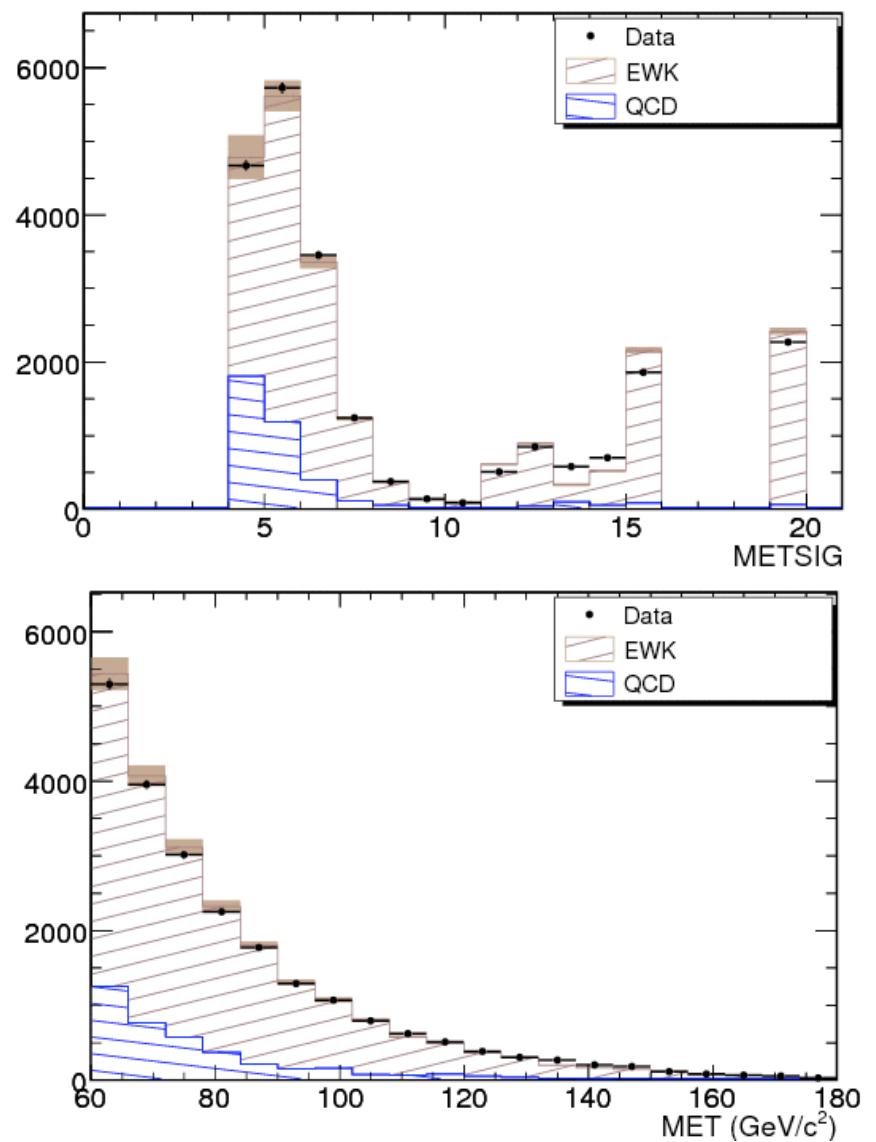
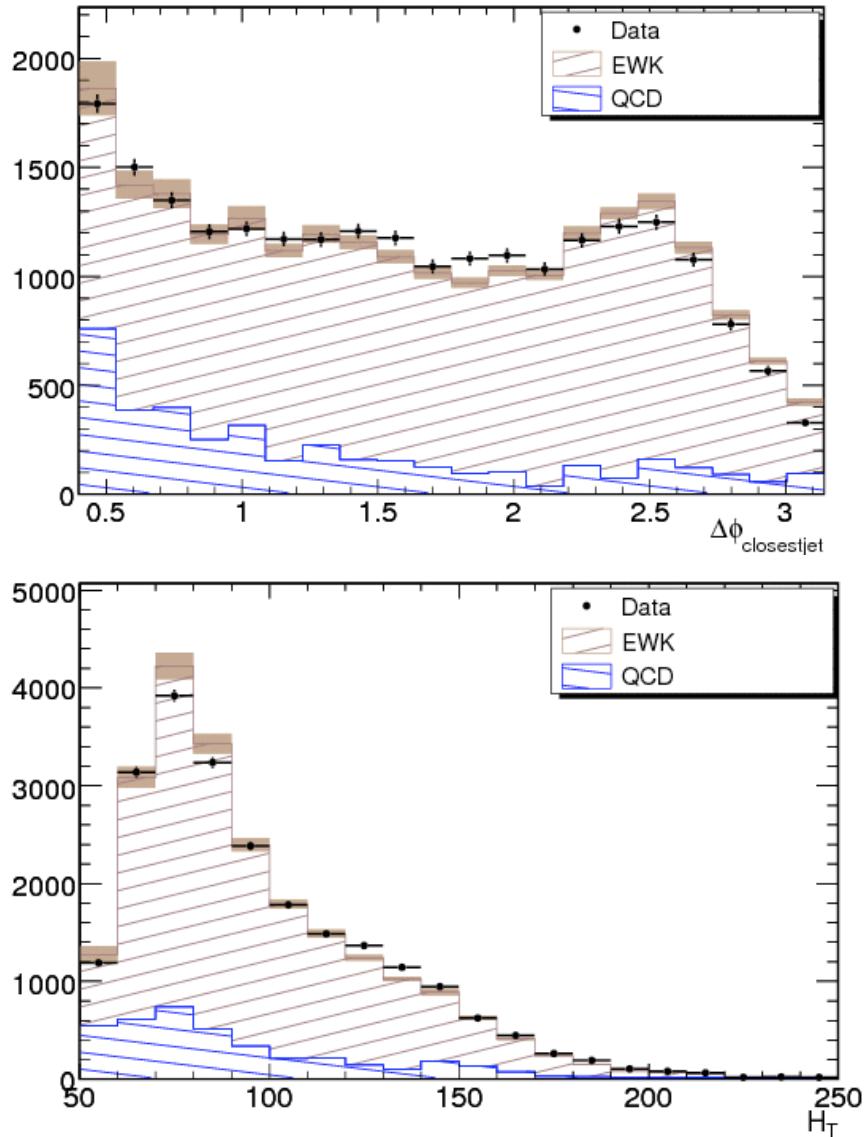
- Allow JES to float in the fit
  - From Final fit:  $0.985 \pm 0.019$
- Parameterize width (Gaussian  $\sigma$ ) as a function of JES

# JER uncertainty

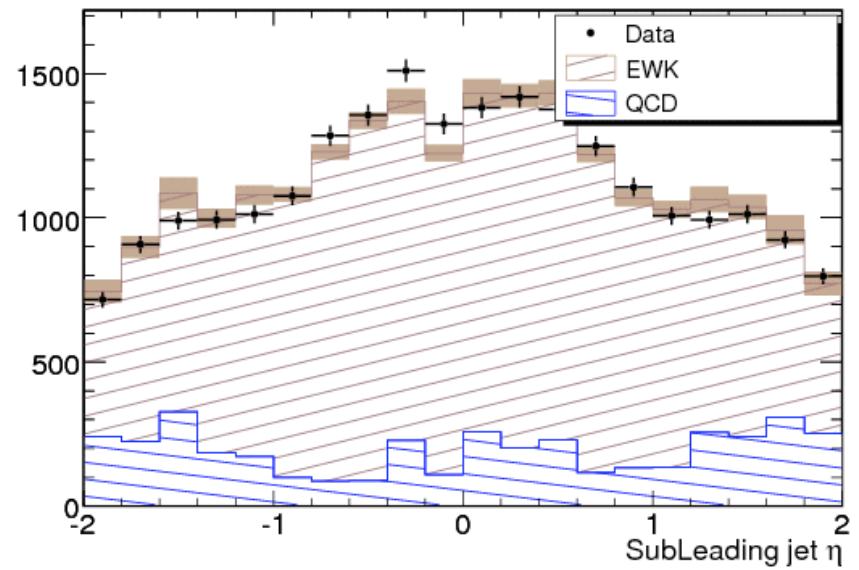
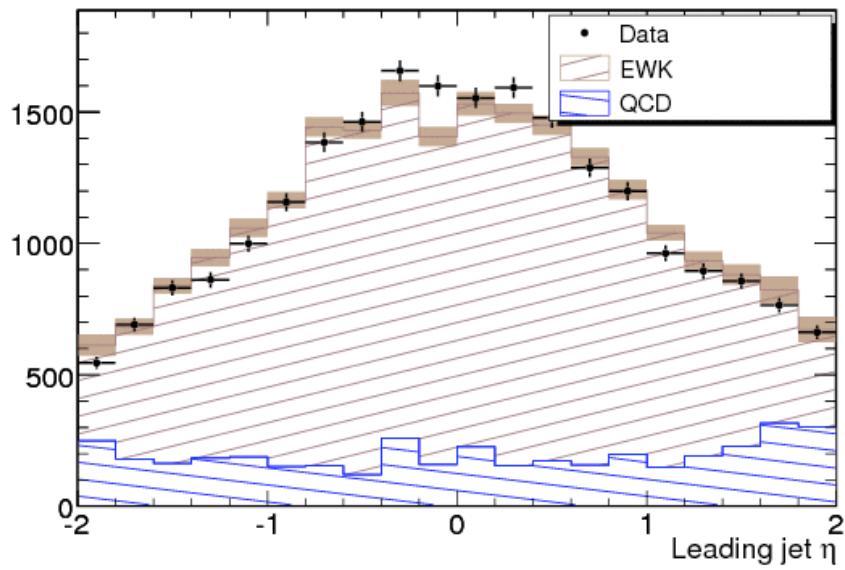
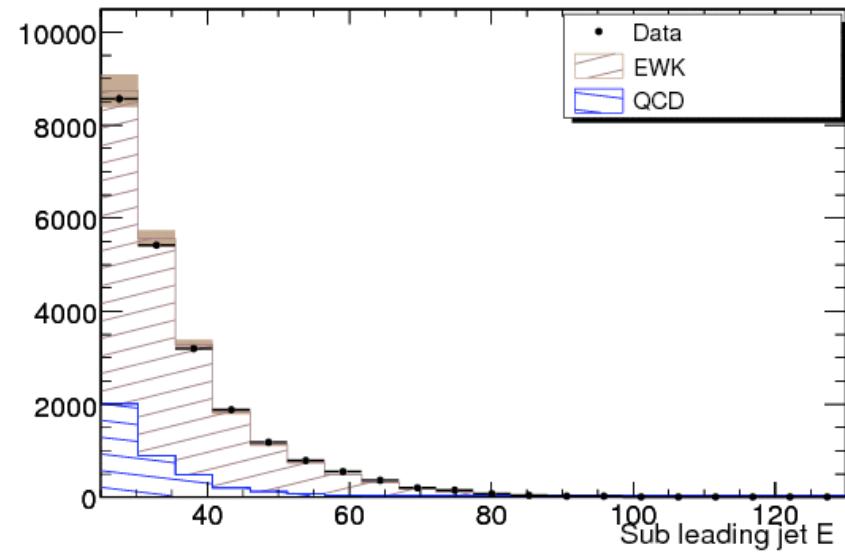
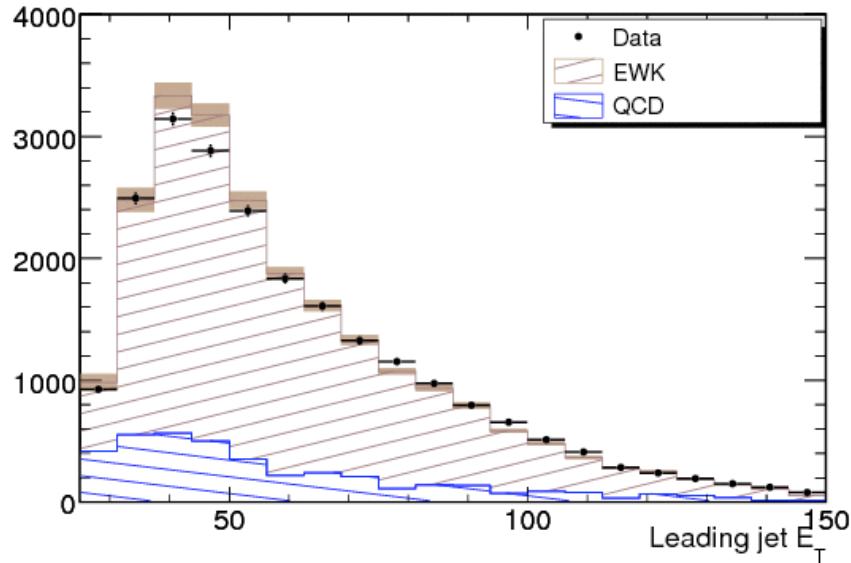


- **JER uncertainty**
  - Nvx=1 vs Nvx>1
  - Fit function
  - $\Delta\phi_{jj}$  cut
  - $E_T(jet3)$  cut

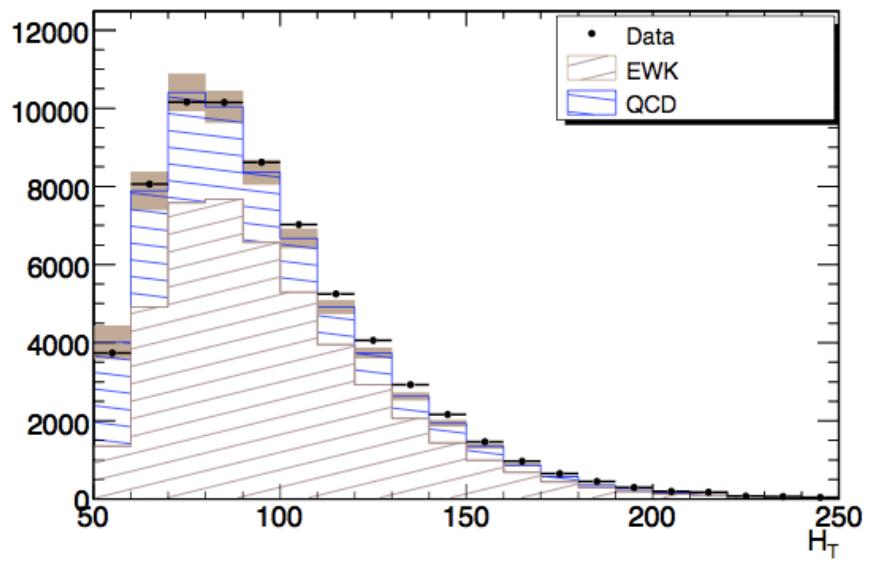
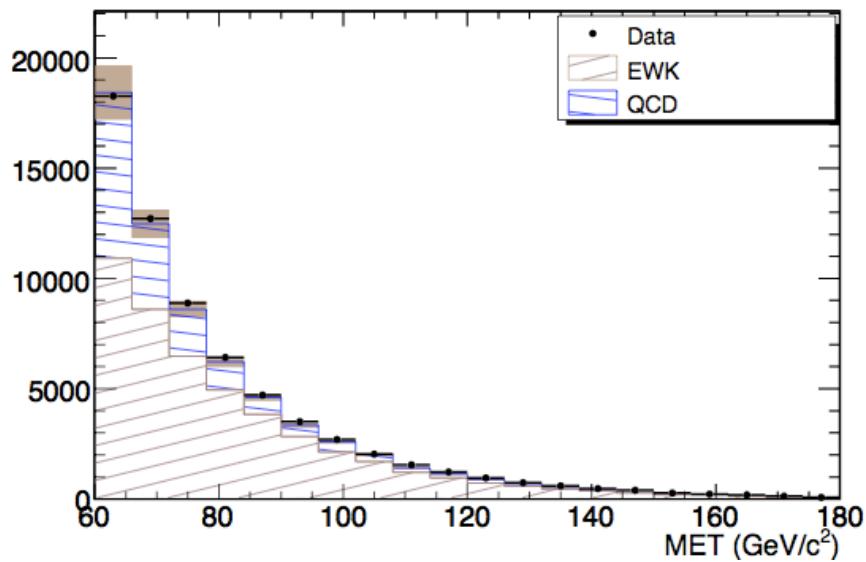
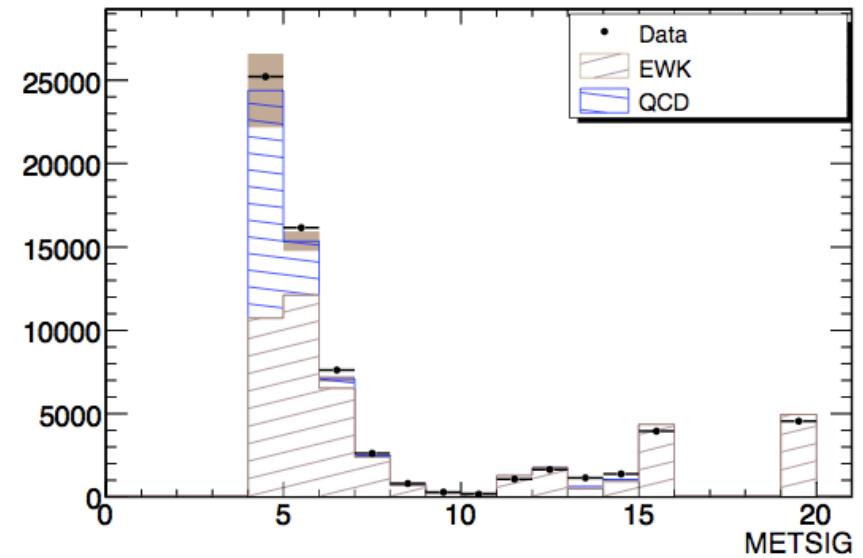
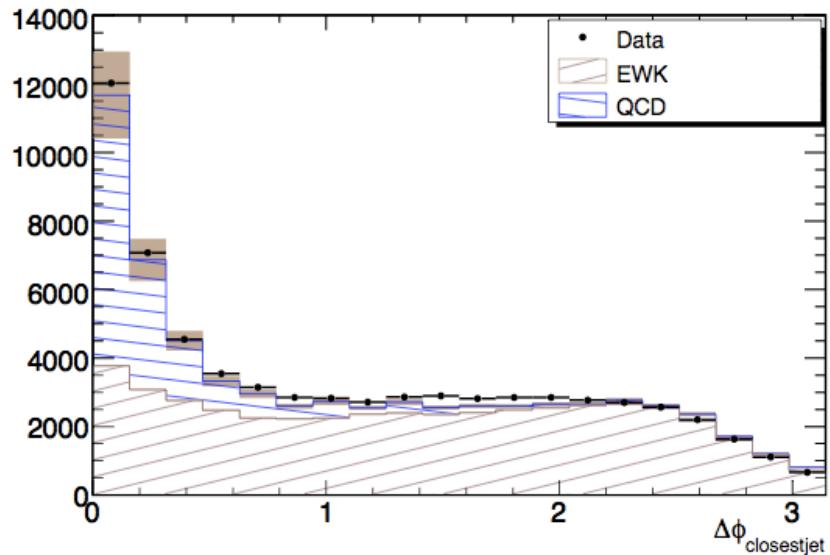
# “Sideband” Kinematics: $40 < M_{jj} < 60$ , $110 < M_{jj} < 160$



# “Sideband” Kinematics: $40 < M_{jj} < 60$ , $110 < M_{jj} < 160$



# No $\Delta\phi_{\text{closest}}$ Cut



# Significance Part-I

- MINUIT reports  $1516/239=6.34\sigma$ 
  - PEs (s+b fit to s+b generated) imply a  $6.45\sigma$
  - $-2\Delta L = \text{LogL}(s+b) - \text{LogL}(b) = 42$ 
    - $\text{TMath}::\text{Prob}(42,1) = 9.1 \times 10^{-11} \rightarrow 6.48\sigma$
- Naïve approach:
  - $\text{stat}^2 + \text{syst}^2 = 234^2 + 144^2 = 275^2$
  - $1516/275 = 5.5\sigma \rightarrow 3.8 \times 10^{-8}$

# Significance Part-II

- Try to estimate the degradation of signal significance by systematic uncertainties
  - Fix all parameters except  $N_{ewk}$  and  $N_{sig}$ 
    - $\Delta L = 22 \rightarrow \text{TMath::Prob}(44,1)=3.3\times 10^{-11} \rightarrow >6\sigma$
  - Use alternative JER and repeat:
    - $\Delta L = 22 \rightarrow \text{TMath::Prob}(44,1)=3.3\times 10^{-11} \rightarrow >6\sigma$
  - Use alternative  $\gamma+jets$  and repeat:
    - $\Delta L = 14 \rightarrow \text{TMath::Prob}(28,1)=1.2\times 10^{-7} \rightarrow 5.3\sigma$
- The smallest significance corresponds to  $5.3\sigma$ 
  - Good agreement with Naïve approach:  $5.5\sigma$